SEVENTH ANNUAL REPORT ON CACAO RESEARCH 1937

IMPERIAL MYCOLOGICAL INSTITUTE
31 AUG. 1938

Via colendi haud facilis.

Price **Five Shillings.**

TRINIDAD:
PRINTED BY THE GOVERNMENT PRINTER,
GOVERNMENT PRINTING OFFICE,
PORT-OF-SPAIN.

1938.

CONTENTS.

A.—BOTANICAL SECTION.

PAGE.

THE BOTANICAL PROGRAMME OF 1937 1

SELF-INCOMPATIBILITY IN CACAO—II 2

A NOTE ON THE BEHAVIOUR OF CACAO FLOWERS AFTER POLLINATION AND ON THE INCIDENCE OF CHERELLE WILT 5

THE INCIDENCE OF CROSS-POLLINATION IN CACAO 9

SOME FACTORS CONTROLLING THE YIELD OF YOUNG CACAO—I 14

STUDENT INVESTIGATION—INCOMPATIBILITY AND POLLINATION IN CACAO ... 19

CACAO—A SUMMARY OF LITERATURE SINCE 1931 20

(B).—CHEMICAL AND ECOLOGICAL SECTION.

THE CHEMICAL PROGRAMME OF 1937 31

PART I—CACAO SOIL INVESTIGATIONS.

(1) SOME GOLD COAST CACAO SOILS—SERIES II 32

(2) MANURIAL EXPERIMENTS ON CACAO IN TRINIDAD—SUMMARY OF RESULTS FOR 1937 40

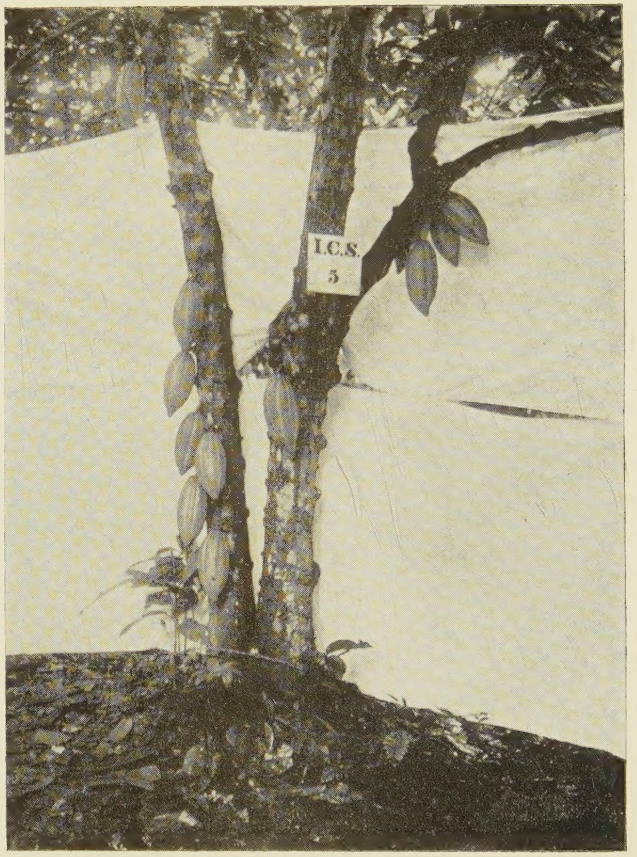
PART II—BIOCHEMISTRY OF CACAO.

(1) OBSERVATIONS ON THE BIOCHEMISTRY OF CACAO KERNEL—I. TANNIN AND CATECHIN 47

SEVENTH ANNUAL REPORT

ON CACAO RESEARCH 1937

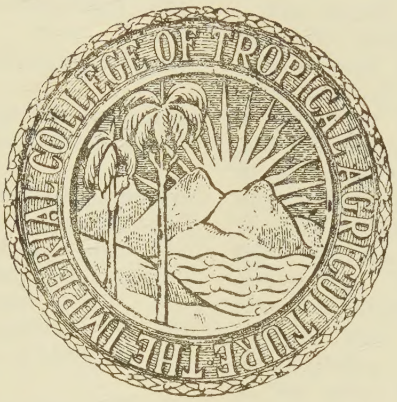
PLATE I.



SELF-INCOMPATIBILITY.

Only one cherelle was produced as a result of a total of 495 self-pollinations on these two trees, but 58 flowers crossed with pollen from the self-compatible I.C.S. 1 resulted in 45 cherelles; 29 of these reached maturity as shown above. (*See* page 3.)

SEVENTH ANNUAL REPORT ON CACAO RESEARCH 1937



Via colendi haud facilis

Price **Five Shillings.**

TRINIDAD:
PRINTED BY THE GOVERNMENT PRINTER,
GOVERNMENT PRINTING OFFICE,
PORT-OF-SPAIN.

1938.

Digitized by the Internet Archive
in 2025

https://archive.org/details/annual-report-on-cacao-research_1937_7

SEVENTH ANNUAL REPORT ON CACAO RESEARCH, 1937

A—BOTANICAL SECTION.

THE BOTANICAL PROGRAMME OF 1937.

By E. E. Cheesman.

During the past year, Mr. O. J. Voelcker has continued his studies of self-incompatibility in Trinidad cacao and the connected problems of fertilization, of which a preliminary account was given in the last Report. The results are sufficiently important to be summarized and emphasised in this introduction.

Our views on compatibility and incompatibility can now be stated as follows:—

1. The existence of self-compatible and self-incompatible trees in Trinidad cacao fields has been confirmed beyond all doubt.

2. The division between the two classes appears on the latest evidence to be clear-cut and permanent. Fourteen incompatible and five compatible trees showed no change of state in a full year of intensive observation.

3. Trees classed as self-compatible will set fruit from hand-pollinations even if they are not setting naturally at the time.

4. Trees classed as self-compatible will set fruit with the pollen of self-incompatible, as well as of other self-compatible, trees.

5. Trees classed as self-incompatible will set fruit if pollinated from a self-compatible tree.

6. Trees classed as self-incompatible will not set fruit if pollinated from other self-incompatible trees.

These conclusions are not all equally well-founded, and it should be recognized that exceptions may yet be discovered, but the first of them is as definite as a biological finding can be. The second conflicts with the idea of "conditional compatibility" put forward in the 1934 Report, but appears to be inescapable. In a separate paper on the behaviour of cacao flowers after pollination, Voelcker shows that self-incompatible trees do in fact vary in their behaviour at different times of the year, to the extent that at some seasons pollination delays abscission of the flower and causes an initial growth of the pistil. It was upon this phenomenon that the provisional theory of a change of state was based, and now that further research has shown that true setting of fruit does not follow, the provisional theory must be withdrawn.

The third conclusion is based on observations of five self-compatible trees, which set freely from hand-pollinations during May. Its significance is as an indicator of the importance of pollinating agents, and it will be followed up.

The fourth and fifth conclusions both confirm previous findings, first noted by Pound in the 1932 Report, and there seems no reason to doubt their general application. The sixth conclusion is the least well-founded, as a generalization, and will be further tested. If self-incompatibility in cacao follows similar lines to self-incompatibility in certain temperate fruit-trees, we should expect to find occasional examples of self-incompatible trees proving fully compatible with each other on crossing. We have not yet had the opportunity of testing this possibility at all exhaustively in cacao.

With the possibility of occasional cross-compatibility reserved, the evidence in favour of the great importance of the self-compatible individuals in the population is still impressive, and leads us on to studies of fertilization. It follows logically from the nature of self-incompatibility that all (or very nearly all) the pods that set naturally on a self-incompatible tree must be the results of cross-pollinations. Unfortunately there appears to be no practicable method of proving directly and conclusively that that is in fact the case. Mr. Voelcker has, however, done what he could to confirm his conclusions from this angle. In his paper on cross-pollination he has been able to show that even on self-compatible trees 50 per cent. of the pods set naturally may be cross-fertilized. This proves cross-pollination to be going on to an extent sufficient to explain the crop on self-incompatible trees. On six trees of the latter class it was possible to prove cross-fertilization in from 67 per cent. to 90 per cent. of the pods produced. The remainder might, so far as the available method would indicate, have been either crossed or selfed. Taking this result in conjunction with the other evidence Voelcker finds "ample justification for assuming all the pods on self-incompatible trees to be the result of cross-fertilization".

This has important bearings on the use of seedling progenies from selected trees. It also raises again the question of the influence of compatibility on final yield. If for any considerable portion of the year it is possible for self-pollination to take place in cacao flowers when agents of cross-pollination are absent, the self-compatible trees will have an obvious advantage, and we might expect self-compatible trees as a class to be higher yielders than self-incompatible trees as a class. At present we lack direct evidence that they are, and have on the contrary the evidence of our I.C. Selections that individually self-incompatible trees may yield extremely well. We need, therefore, further knowledge of pollinating agents and their mode of action, and also direct comparisons of the self-compatible and self-incompatible components in existing populations.

The first seedling progenies from I.C.S. trees are now coming into bearing at River Estate, and detailed observations are being kept on 600 of these young trees. They were planted before the wide incidence of self-incompatibility was fully realized, and it is now known that four of the six parents used are self-incompatible. Also, open pollinated seed was used, and consequently all the progenies are segregating compatible and incompatible individuals. The observations were begun in July, 1937, by Mr. Voelcker and are being continued by Mr. Cope, in the hope of assessing the relative importance of compatibility and other factors in determining yield. It is, of course, too early to begin drawing conclusions from them, but it is interesting to note that in the first six months the young trees classified as self-compatible have set roughly four to five times as many cherelles as those classified as incompatible.

The work of the year under review includes some investigations into the nature of incompatibility by a post-graduate student, Mr. A. F. Posnette, and an abstract of his dissertation is included in this Report. It completes the record of the strictly experimental work, but is followed by a review of literature by Mr. Voelcker which I think will be found widely useful. Since 1930 many new facts have come to light both within and outside the British Empire, and Mr. Voelcker has brought them together for the benefit of those whose library facilities may be more limited than those of a research centre.

The technical papers appended do not, however, cover all the activities of the Botanical Section during the year. Routine propagation of selected material has been carried on steadily by Mr. G. E. L. Spencer, and combined with certain investigations in propagation methods, notably in the use of plant hormones for accelerating rooting. Details of these experiments will be published later, but it may be noted here that "Hortomone A" in suitable concentrations has been found to improve the rooting of cacao cuttings quite substantially.

During the year the first field experiment to include cuttings was planted at River Estate, by courtesy of the Trinidad Department of Agriculture, and the young plants are doing well. Six randomized blocks of 96 trees each serve for comparison of six scion clones and four propagation methods. A number of seedlings raised from self-pollination of self-compatible selections have also been planted elsewhere.

Mr. Voelcker has now returned to his substantive post in the Department of Agriculture, Nigeria, from which he had been seconded. The research programme has received much benefit from his association with it, as the whole of this Report bears witness, and it is with pleasure that acknowledgment of his services is here recorded. Mr. F. W. Cope was appointed Junior Botanist for Cacao Research in September, 1937, and took up duties in that month.

SELF-INCOMPATIBILITY IN CACAO–II.

By O. J. Voelcker.

In the previous Report (1) a short paper was presented to record the behaviour of Imperial College Selection trees at River Estate when self-pollinated. It will be remembered that out of 19 trees tested for self-incompatibility between July, 1936, and January, 1937, only five were self-compatible, and that there was no indication of any change from self-incompatibility to self-compatibility during that period. The present paper records further work on these trees to cover the first heavy flowering flush in May. In July, August and September a number of cross-pollinations were made between certain of these trees.

All the pollinations were made on guarded flowers. For the crosses, pollen was obtained from freshly opened flowers which were picked and carried to the trees over damp moss in tins. While only the anthers of the same flower were used in self-pollinations, anthers from more than one flower were, if necessary, taken for the crosses. Imperial College Selection 83 only yielded pollen sparsely, and rarely did one flower supply sufficient pollen. The male parentage of the crosses was determined by the number of flowers available, and I.C.S. 1 was notably the only freely flowering self-compatible tree during the period

Unlike the self-pollinations in May, which were carried out daily over one fortnight, each set of crosses was made over a period of only three days, and it is important to bear this in mind when comparing the results of crosses with those of self-pollinations averaged from a year's work. The complete record of results, which includes figures from the paper in the previous Cacao Report (1936), is presented in Table I.

It will be seen that the May self-pollinations follow very closely the behaviour of those done in the period July to January. The self-incompatible trees remain self-incompatible, and the self-compatible do not alter. The results of cross-pollination bear out Pound's (2, 3) conclusions that self-incompatible trees crossed by self-incompatibles set very poorly or not at all, but that crossed by self-compatibles setting is satisfactory; self-compatibles will set with pollen from self-incompatible trees. This is confirmed by the behaviour of the 12 self-incompatible trees when crossed by the self-incompatible I.C.S. 83 or I.C.S. 97, yielding only one fruit set after 14 days from 245 pollinations. But crossed by the self-compatible I.C.S. 1 these trees yielded 190 fruit set from 228 pollinations. The self-compatible trees crossed by the self-incompatible I.C.S. 5, I.C.S. 83 and I.C.S. 97 gave the favourable result of 70 fruit set from 84 pollinations.

Discussion.

The results obtained show conclusively that no change from the self-incompatible state to the self-compatible state has taken place on the trees examined over a period of a year, and there seems every reason to believe that other self-incompatible trees behave in a similar fashion. The conclusion that these self-incompatible trees set all their fruit as a result of cross-pollination is considered in a paper on that subject in this report.

If further work proves that these self-incompatible trees cannot even set fruit with pollen from other self-incompatibles, the importance of self-compatible trees in a field is enormous. Not only do they provide some pollen for fertilization of their own flowers, but they also have to supply all the pollen for the incompatible trees, and without this pollen, yields would sink to zero. To support this somewhat alarming conclusion, the results of the May pollinations contribute substantially.

Table I.

Tree.	Self-Pollinations.						Cross Pollinations.					
	July, 1936	Jan., 1937	May, 1937.		Total.		By I.C.S. 1.		By I.C.S. 83.		By I.C.S. 97.	
	Number pollinated	On after 14 days	Number pollinated	On after 14 days	Number pollinated	On after 14 days	Number pollinated	On after 14 days	Number pollinated	On after 14 days	Number pollinated	On after 14 days
360	253	1	45	0	298	1	—	—	—	—	—	—
I.C.S. 100	55	2	52	0	107	2	17	16	3	0	7	0
I.C.S. 2	158	0	48	0	206	0	17	14	10	0	10	0
I.C.S. 3	50	1	65	0	115	1	29	25	11	0	8	0
I.C.S. 83	114	5	31	0	145	5	21	17	—	—	13	0
I.C.S. 86	42	3	41	3	83	6	16	13	3	0	6	0
I.C.S. 99	10	0	58	0	68	0	12	8	3	0	5	0
I.C.S. 90	21	0	—	—	21	0	—	—	—	—	—	—
I.C.S. 20	76	0	30	0	106	0	10	8	11	0	21	0
I.C.S. 97	250	0	59	0	309	0	20	17	24	0	—	—
I.C.S. 4	111	0	31	0	142	0	17	15	3	0	10	0
I.C.S. 94	9	0	79	2	88	2	11	10	17	0	8	0
I.C.S. 5	318	0	62	0	380	0	29	20	17	0	14	0
I.C.S. 17	161	2	52	0	213	2	29	27	26	0	15	1
							By I.C.S. 5		By I.C.S. 83		By I.C.S. 97	
V14	117	81	18	12	135	93	16	14	8	7	8	8
I.C.S. 1	35	17	39	26	74	43	15	13	1	1	5	5
I.C.S. 6	24	17	55	33	79	50	3	1	—	—	1	1
I.C.S. 7	35	22	33	15	68	37	10	8	7	4	7	6
I.C.S. 9	24	15	22	9	46	24	3	2	—	—	—	—

Self-incompatibles. Self-pollinations, 2,282 giving 19 or **0.8** per cent. set at 14 days.
Self-incompatibles. Crossed by I.C.S. 83 and I.C.S. 97, 245 giving 1 or **0.04** per cent. set at 14 days.
Self-incompatibles. Crossed by I.C.S. 1, 228 giving 190 or **83.5** per cent. set at 14 days.
Self-compatibles. Self-pollinations, 402 giving 247 or **61.5** per cent. set at 14 days.
Self-compatibles. Crossed by I.C.S. 5, I.C.S. 83, I.C.S. 97, 84 giving 70 or **83** per cent. set at 14 days.

Well recognized throughout Trinidad, and put into concrete form by Pyke (4) and Pound (3) is the fact that a heavy flowering flush occurs after the first rains which terminate the dry season. This burst of flowers occurs in May or June according to the season. The amount of setting which takes place as a result of this flowering is of the smallest, and the flowering is considered of no importance to the planter—just a matter of caprice on the part of the trees which does no one any good and is delightfully termed "crazy flowering." Suggestions are put forward that the climatic conditions are wrong, or more generally that there is an indefinable something astray with the flowers which prevents setting. Bound up with this is the view that intensity of setting is determined by the nutritional status of the tree, which must, presumably, be at a very low level during the first May-June flowering flush. The results of hand-pollinations on self-compatible trees during this period show that there is nothing wrong with the flowers themselves. Given pollen, they set as freely as at any other time of the year. The writer would conclude that the very poor natural setting in May-June is entirely due to inadequate pollination by compatible pollen and is brought about by the absence of agents of pollination, themselves dependent on rainfall and climatic conditions. Where pollination has been provided on the five self-compatible trees during a fortnight of the May flowering a total of only 167 pollinations yielded 38 ripe pods

The natural yields resulting from the May flowering are practically zero, and this is due to the very poor setting and not to excessive cherelle shrivelling. This unfortunate result would presumably occur throughout the year were it not for the self-compatible trees later acting as pollinators, the agents of pollination increasing rapidly after the first rains.

If this view is confirmed, artificial fertilizers, soil cultivation, pruning and other such operations can have no effect on the percentage of setting, except in so far as they affect the incidence of the agents of pollination. But by increasing the number of flowers produced or by lessening the losses after setting the final yield may be greatly influenced. Pound (5) mentions that certain manures are "beneficial to setting" and caused a "significant increase in the intensity of fruit setting", but as no figures were given for any alteration in the number of flowers produced as a result of the fertilizers, these conclusions may simply record the fact that flowering was much heavier; and the *percentage* of setting remaining the same, the total setting was greater.

Table I presents a mass of figures. It does not record the vivid impressions of the writer. Trees, such as I.C.S. 5, I.C.S. 97 and I.C.S. 2, are free flowering, and for a total of some 85 days he has self-pollinated 895 flowers on these alone. Not one remained after a fortnight. Then, for only three days, 66 cross pollinations with the compatible pollen from I.C.S. 1, resulted in 51 strongly growing cherelles at a fortnight old. The conclusions drawn in this paper are based only on the figures, but in every respect they conform to the angle from which the writer views the subject of fruit setting.

The opinion that lack of setting is due to lack of fertilization, itself dependent on adequate compatible pollen reaching the stigmata, is no new view point. Harland (6) has presented similar conclusions based on inefficient pollination but he did not realize that the pollen must also be compatible. Pound (3) and Pyke (4) have commented on the advantages of trees capable of setting fruit with their own pollen, thereby implying the importance of avoiding the necessity for agents of cross-pollination. Whether increased yield would result from increased setting over longer periods is still a question which remains unproved. The writer must again be excused for pressing a comparison of Trinidad yields with those from West Africa. Self-incompatibility has been shown to be a feature of the Trinidad cacao population; it does not appear to occur in Nigeria. The following yields are presented for comparison (7):

River Estate, Trinidad. Average for first eleven years of cropping.

Spacing 6 × 6 ... 352 lb. per acre.
Spacing 8 × 8 ... 341 lb. per acre.

The fields at this close spacing may be considered in as good a state of cultivation as the bulk of Nigerian cacao at that age, and the River Estate trees show quite, if not more, vigorous growth. The yields are, however, well below the West African standards generally accepted. It is hoped that critical experiments will in due course prove or falsify the assumption that the presence of a high proportion of self-incompatible trees adversely affects yields.

The importance of discovering the natural agent of pollination, the life history and the environment favourable for its multiplication seems great. Until this information is established little practical value can result directly from this work on self-incompatibility, except in so far as it shows with what difficulty self-incompatible trees yield at all.

Results and Conclusions.

1. The trees examined show no change from self-incompatibility to self-compatibility or *vice versa*.

2. The self-incompatible trees set no fruit when crossed by the self-incompatible I.C.S. 83, and only one when crossed by the self-incompatible I.C.S. 97.

3. But the self-incompatible trees set very freely when crossed by the self-compatible I.C.S. 1.

4. The self-compatible trees set freely with pollen from the self-incompatible I.C.S. 5, I.C.S. 83, I.C.S. 97.

5. When flowering was intense and natural setting very low in May, hand pollinations on the self-compatible I.C.S. 1, I.C.S. 6, I.C.S. 7, I.C.S. 9 and V14 resulted in a high percentage set.

6. It is concluded that the absence of self-compatible trees from a cacao field would reduce the yield of the remaining trees to zero.

References.

1. Voelcker, O. J.—Self-Incompatibility in Cacao. *Sixth Annual Report on Cacao Research*, 1936.
2. Pound, F. J.—Studies of Fruitfulness in Cacao. II. Evidence for Partial Sterility. *First Annual Report on Cacao Research*, 1931.
3. Pound, F. J.—Studies of Fruitfulness in Cacao. III. Factors Affecting Setting. *Second Annual Report on Cacao Research*, 1932.
4. Pyke, E. E.—The Physiology of Cacao. General Observations of Growth, Flowering and Fruiting. *Second Annual Report on Cacao Research*, 1932.
5. Pound, F. J.—Studies of Fruitfulness in Cacao. VI. First and Second Year Observations in an Experiment Designed to Test the Gross Effects of Nitrogen, Potassium and Phosphorus on the Cacao Tree. *Fourth and Fifth Annual Reports on Cacao Research*, 1934 and 1935.
6. Harland, S. C.—Studies in Cacao. Part I. The Method of Pollination. *Ann. Appl. Biol.* 12 (1925) 403-409.
7. —— Cultural Experiments on Cacao at River Estate. Distance Spacing Experiments *Administration Report of the Director of Agriculture, Trinidad and Tobago*, 1936.

A NOTE ON THE BEHAVIOUR OF CACAO FLOWERS AFTER POLLINATION AND ON THE INCIDENCE OF CHERELLE WILT.

By O. J. Voelcker.

A record was kept of the time between pollination and the falling of the flower, young fruit or cherelle on all the hand-pollinated trees mentioned in the previous papers on self-incompatibility (1). Owing to the routine methods adopted, it has been necessary to group together all losses on the first, second and third days after pollination, but thereafter the figures are considered to demonstrate with a fair degree of accuracy the period between pollination and falling. Occasional days absent from River Estate introduce some error, and this has been accepted as inevitable.

Following on Pound's (2) conclusion that there was a seasonal change between self-incompatibility and self-compatibility, two tables are presented, the one to cover the first flowering flush in May, when the author found a high degree of self-incompatibility, the other to cover self-pollinations made in the period July to December during which Pound noticed a change to the self-compatible state.

" Controls " in Tables II and III mean flowers guarded against natural pollination but not actually hand pollinated.

The chief features of interest are in the clear cut difference of behaviour between the self-incompatible and self-compatible trees, which have been grouped accordingly, and the maintenance of individual trees within these two groups irrespective of the season. But it will be noticed that a greatly increased fall of flowers occurs within the first three days of the May pollinations, and in this respect a seasonal variation is clearly apparent. Moreover there is a tendency for flowers from incompatible trees to show some growth of the pistil after self-pollination, and this no doubt explains the statement by Pound (2) that " several of the eleven self-incompatible trees came very near to setting." This initial growth of the pistil to some extent varies within the self-incompatible group. Thus I.C.S. 94, I.C.S. 3 and I.C.S. 100 appear to set a reasonable percentage at both seasons, if the setting limit is taken at four or five days. I.C.S. 97 is an example of a self-incompatible tree " setting " by hand poorly in May but better during the later months.

This variation in the length of time between pollination and falling must be recognized in determining whether a tree is self-compatible or incompatible; for this reason the greatest importance is attached to the time interval at which a flower is considered to be "set." A six day interval appears satisfactory for the May flowering, but scarcely so for the later months; especially is this the case if circumstances compel an examination at less than six days. There are practical advantages in taking the setting limit at 14 days, and little error will result if this limit be reduced or expanded by two or three days.

Not shown by the tables, but again of undoubted importance, is the daily fluctuation in the effect of pollination. Observation suggests that this is due to the quantity of pollen placed on the stigma, which may well be insufficient if climatic or other conditions are unfavourable. In testing trees for self-compatibility it would appear advisable to make a number of pollinations on several days.

The causes of the initial pistil growth with incompatible pollinations are not known. Posnette (3) has suggested that possibly the pollen tubes do not reach the ovary, and that fertilization does not take place. A similar delay in the abscission of apple flowers pollinated with incompatible pollen has been shown to occur by Bryant (4) who found that pollination alone, without fertilization, was responsible for delaying the degeneration of the flowers. A point of possible interest has been observed by the present writer. Flowers occurring in star brooms (witch-broom (*Marasmius perniciosus*, Stahel) infected cushions) often show an exceptional proportion apparently fertilized. It seems almost impossible for this high proportion to have been pollinated naturally, and it is suggested that the fungus stimulates the pistil in much the same manner as an incompatible pollination.

Table II.

HAND SELF-POLLINATED FLOWERS.

NUMBER REMAINING ON TREES—DAILY INTERVALS.

20TH MAY TO 1ST JUNE.

Tree.	No. Poll.	Days.												Over 14 days
		1, 2, 3	4	5	6	7	8	9	10	11	12	13	14	
Control	110	0	0	0	0	0	0	0	All incompatible trees					0
360	45	7	2	2	2	1	0	0	0	0	0	0	0	0
I.C.S. 100	52	26	11	9	6	4	3	0	0	0	0	0	0	0
I.C.S. 2	48	12	4	2	0	0	0	0	0	0	0	0	0	0
I.C.S. 3	65	60	35	7	1	0	0	0	0	0	0	0	0	0
I.C.S. 83	31	8	4	2	0	0	0	0	0	0	0	0	0	0
I.C.S. 86	41	27	11	5	5	5	3	3	3	3	3	3	3	3
I.C.S. 99	58	10	0	0	0	0	0	0	0	0	0	0	0	0
I.C.S. 90	No Flowers													
I.C.S. 20	30	23	10	0	0	0	0	0	0	0	0	0	0	0
I.C.S. 97	59	12	2	1	0	0	0	0	0	0	0	0	0	0
I.C.S. 4	31	18	4	1	0	0	0	0	0	0	0	0	0	0
I.C.S. 94	79	67	55	24	12	6	5	5	4	4	4	2	2	2
I.C.S. 5	62	49	26	7	5	1	1	1	1	0	0	0	0	0
I.C.S. 17	52	10	5	2	0	0	0	0	0	0	0	0	0	0
Total	653	329	169	62	31	17	12	9	8	7	7	5	5	5
Per cent.	100	50.0	25.5	9.1	4.4	2.3	1.6	1.2	1.1	1.0	1.0	0.7	0.7	0.7
Control	17	0	0	0	0	0	0	0	All compatible trees					0
V14	18	13	13	13	13	13	13	12	12	12	12	12	12	12
I.C.S. 1	39	39	39	32	30	28	28	28	27	27	27	26	26	26
I.C.S. 6	55	52	47	46	43	42	40	38	37	33	33	33	33	33
I.C.S. 7	33	29	28	27	24	22	19	19	18	17	17	15	15	15
I.C.S. 9	22	20	18	15	15	14	12	10	9	9	9	9	9	9
Total	167	153	145	133	125	119	112	107	103	98	98	95	95	95
Per cent.	100	91.6	86.8	79.6	74.8	71.2	67.0	64.0	61.6	58.6	58.6	56.9	56.9	56.9

Self-Incompatible trees, Percentage "Set" at 6 days 4.4; at 14 days **0.7**.
Self-Compatible trees, Percentage "Set" at 6 days 74.8; at 14 days **56.9**.

Table III.

HAND SELF-POLLINATED FLOWERS.

NUMBER REMAINING ON TREES—DAILY INTERVALS.

17TH JULY TO 9TH JANUARY.

Tree.	No. Poll.	Days. 1, 2, 3	4	5	6	7	8	9	10	11	12	13	14	Over 14 days
Control	115	2	0	0	0	0	0	0	All incompatible trees					0
360	254	152	71	40	24	16	9	6	2	2	1	1	1	1
I.C.S. 100	55	38	23	14	8	2	2	2	2	2	2	2	2	2
I.C.S. 2	158	118	80	40	16	2	1	0	0	0	0	0	0	0
I.C.S. 3	50	44	32	23	13	8	3	3	2	2	1	1	1	1
I.C.S. 83	114	66	37	27	17	10	9	8	6	6	5	5	5	5
I.C.S. 86	42	35	30	20	10	7	7	5	4	4	4	4	3	3
I.C.S. 99	10	6	6	3	2	1	1	0	0	0	0	0	0	0
I.C.S. 90	21	16	9	6	4	1	0	0	0	0	0	0	0	0
I.C.S. 20	76	61	34	12	5	4	2	1	1	0	0	0	0	0
I.C.S. 97	250	186	101	51	19	5	3	3	1	1	0	0	0	0
I.C.S. 4	111	89	52	31	19	5	3	0	0	0	0	0	0	0
I.C.S. 94	9	9	8	5	5	2	1	1	0	0	0	0	0	0
I.C.S. 5	318	255	182	114	41	16	7	3	3	1	1	0	0	0
I.C.S. 17	161	140	114	83	54	33	21	12	7	6	3	2	2	2
Total	1,629	1,215	779	469	237	112	69	44	28	24	17	15	14	14
Per cent.	100	74.6	47.9	28.9	14.7	7.0	4.4	2.9	1.9	1.6	1.2	1.0	0.9	0.9
Control	7	0	0	0	0	0	0	0	All compatible trees					0
V14	117	103	97	95	94	89	88	87	87	85	85	85	81	81
I.C.S. 1	35	30	23	22	22	20	20	20	18	18	17	17	17	17
I.C.S. 6	24	20	20	18	18	18	18	18	18	18	17	17	17	17
I.C.S. 7	35	26	26	26	26	26	26	26	25	24	24	22	22	22
I.C.S. 9	24	20	16	15	15	15	15	15	15	15	15	15	15	15
Total	235	199	182	176	175	168	167	166	163	160	158	156	152	152
Per cent.	100	84.7	77.5	75.0	74.6	71.6	71.2	70.8	69.5	68.2	67.4	66.6	64.9	64.9

Self-Incompatible trees, Percentage "Set" at 6 days 14.7; at 14 days **0.9.**

Self-Compatible trees, Percentage "Set" at 6 days 74.6; at 14 days **64.9.**

Cherelle Wilt.

A record of cherelle shrivelling is presented in Table IV for those fruit set as a result of self-pollination on the five compatible River Estate trees. A comparison is made with similar records of six Nigerian trees, the figures having been abstracted from "A Study of Controlled Pollination in Cacao" (5). Both sets of figures cover a complete year and are the result of daily observations. Wilting has been recorded from the first signs of yellowing or cessation of growth. Death of cherelles by disease or damage is included in the figures, but is not considered to affect in any great degree the general comparison.

In examining the figures in Table IV it must be remembered that they are averaged from several trees over a whole year, and that the number of flowers hand-pollinated each day does not indicate the periods of intense flowering. It is important to bear this in mind since the results are contradictory to the data collected by Rounce and Smart (6) and others. These authors showed clearly that cherelle wilt was most prevalent about 50 days from fertilization under natural conditions, and suggested that this was caused by some internal biochemical change resulting from the preliminary growth of the embryo. Under the natural conditions in which previous records of shrivelling have been collected, it has been shown that flowering, setting, flushing and cherelle wilting proceed in discontinuous jerks. Therefore the danger zone occurring about 50 days from pollination may only represent the fact that a physiological crisis has occurred as a result of a heavy natural set seven to eight weeks earlier, or that a flush of growth follows the flowering or setting cycle by this period.

Table IV.

INCIDENCE OF CHERELLE WILT.

Number Self-Pollinated.	6 Self-Compatible trees Nigeria.		5 Self-Compatible trees River Estate.	
	532		402	
Fallen before 15th day	212	40.0%	153	38.3%
Shrivelled 15th-21st day	20		24	
22nd-28th ,,	18		16	
29th-35th ,,	25		19	
36th-42nd ,,	30		18	
43rd-49th ,,	25		17	
50th-56th ,,	21		13	
57th-63rd ,,	13		7	
64th-70th ,,	8		10	
71st-77th ,,	10		13	
78th-84th ,,	4		7	
85th-91st ,,	2		7	
Total fallen 15th-91st day....	176	33.0%	154	38.5%
Number harvested or diseased over 91 days old	144	27.0%	93	23.2%

In Table IV the discontinuous natural jerks of flowering and setting have been largely eliminated, and an even setting of a few flowers each day substituted. Any physiological crises produced in the trees by a growth flush, or for other reasons, can therefore influence approximately equal number of cherelles of all ages. And, it will be noticed, the seven to eight week danger zone has disappeared. The conclusion is drawn that the initial growth of the embryo, which Cheesman (7) has shown to take place about 50 days from fertilization is not a cause of cherelle wilt, but that physiological phenomena within the tree, and not within the cherelle, are of primary importance in determining whether wilting will occur.

The figures for the six Nigerian trees have been presented for comparative purposes, the routine in the collection of the data being the same as that adopted for the five River Estate trees. In most respects a comparison would be considered invalid; the Nigerian trees are growing under totally different soil and climatic conditions, they were only 20 years old compared with an average of about twice that age for the five River Estate trees. The Nigerian trees are representative of the lower range of Forastero and these are compared with individuals within the highest types of that class. The only outstanding features the two groups have in common is their, self-compatibility and their general good health. Table IV shows a response to self-fertilization remarkable for its similarity.

References.

1. Voelcker, O. J.—Self-Incompatibility in Cacao. *Sixth and Seventh Annual Reports on Cacao Research*, 1936 and 1937.

2. Pound, F. J.—Studies of Fruitfulness in Cacao. V. Conditional Self-Compatibility and its Implications. *Fourth Annual Report on Cacao Research*, 1934.

3. Posnette, A. F.—Incompatibility and Pollination in Cacao. MSS. Dissertation in Library of the Imperial College of Tropical Agriculture, 1937.

4. Bryant, L. R.—A Study of Factors Affecting the Development of the Embryo Sac and Embryo in the McIntosh Apple. *Univ. New Hampshire Exp. Sta. Tech. Bull.* No. 61, 1935.

5. Voelcker, O. J.—A Study of Controlled Pollination in Cacao. *Eleventh Bull. of the Dept. Agriculture, Nigeria*, 1936.

6. Rounce, N. V. and Smart, H. P.—The Shrivelling of Pods in Theobroma Cacao. MSS. Dissertation in Library of the Imperial College of Tropical Agriculture, 1928.

7. Cheesman, E. E.—Fertilization and Embryogeny in Theobroma Cacao. L. *Ann. Bot.* 41 (1927,) 107-126.

THE INCIDENCE OF CROSS-POLLINATION IN CACAO.

O. J. Voelcker.

Although considerable evidence of a general nature has in the past been brought forward to show that cross-pollination in cacao takes place, the subject was considered of little practical importance. Seed selection from outstanding mother trees has been the practice over a number of generations in the more progressively run estates, but the resulting progeny has often led to some disappointment. This is only to be expected among such a heterogenous population as the Trinitario group even if self-fertilization were the rule, but the very nature of heterogeneity implies frequent cross-pollination, and that, in turn, the influx of possibly undesirable genes from the unknown and completely ignored male parent. The first serious attempt to estimate the degree of natural cross-pollination in cacao was undertaken by Harland and Frecheville (1). These authors concluded that about 30 per cent. of the pods borne by trees in Trinidad were the result of natural cross-pollination. Since then the discovery of self-incompatibility among Trinidad trees has revived interest in cross-pollination.

The present paper records the results obtained from the application of Harland and Frecheville's methods to material which is of direct interest to Trinidad planters. The trees from which progenies have been examined are Imperial College Selections situated on River Estate, and their behaviour with respect to self-compatibility or incompatibility is described and discussed in the Sixth and present Annual Reports on Cacao Research.

Genetics of Axil Spot.

It is necessary briefly to restate Harland and Frecheville's hypothesis. These authors showed that axil spot in cacao was due to two complementary Mendelian factors designated as follows :—

AB	Ab	aB	ab
Spot present.	Spot absent.		

From this it follows that :—

1. If self-fertilized a tree with no spot will only give progeny with no spot.

2. If self-fertilized a tree with spot will either give progeny all having spot or will give progeny with spot to no spot in the proportion of 9 : 7 or 3 : 1.

3. If cross-fertilized by a tree with no spot a tree with no spot will give progeny as follows :—
   (*a*) all without spot.
   (*b*) some with and some without spot in the proportions of 1 : 1 or 1 : 3.
   (*c*) all with spot.

4. If cross-fertilized by a tree with spot, a tree with no spot will give progeny as follows : —
   (*a*) all with spot.
   (*b*) some with and some without spot in the proportions 1 : 1, 3 : 1, 3 : 5 or 1 : 3.

5. If cross-fertilized by a tree with spot, a tree with spot will give progeny as follows :—
   (*a*) all with spot.
   (*b*) some with and some without in the proportions 3 : 1 or 9 : 7.

Harland and Frecheville also noted a complete correlation between axil spot and pod colour ; trees with no axil spot have pods ripening yellow, though in young stages there may be a slight reddish flush, whereas trees with spot have full red pods. Since axil spot is often difficult to see, except in seedlings, the pod colour is useful in determining the presence or absence of spot in mature trees. It will be noticed that progeny resulting from cross-pollination may segregate into one of a number of different ratios of spot to no spot depending on the genetic make up of the male and female. These ratios are fixed and definite for each combination, and where abnormal ratios occur pollination by more than one male parent is to be suspected.

Other Mendelian Characters.

Wellensiek (2) has established the fact that the colour of the bean depends on genetic factors ; but these factors are complex and have not yet been fully explored. All that is at present known is that a tree grown from a pure white bean will produce only pure white beans if the flowers are self-fertilized. Purple beans which occur from such a tree are the result of cross-pollination. The colour, too, of the hypocotyl shortly after a bean germinates appears to be determined by genetic factors. The amount of anthocyanin pigment was found to be closely correlated with axil spot. A germinating bean with no pigment in the hypocotyl eventually gave rise to a seedling with no axil spot at the base of the leaf petiole, while beans showing red pigment in the hypocotyl later developed into seedlings possessing axil spot. Very faint hypocotyl pigment often made classification into presence or absence difficult.

Methods Adopted.

With few exceptions all pods from 17 River Estate Imperial College Selection trees were grown as single pod progenies during the main 1936-37 season. Before planting, the beans were freed from mucilage, and the tip of each removed to allow examination of bean colour. After germination the presence or absence of pigment in the hypocotyl was noted. The seedlings were then allowed to grow until axil spot determinations could be made. When it became certain that a very close correlation existed between hypocotyl pigment and axil spot no further records were taken of hypocotyl pigment ; this simplified the work considerably and it was found that the determination of axil spot by itself was reliable and easy.

The same procedure was adopted for self-fertilized pods.

Bean colour was classified into four groups; dark purple, purple, light centred purple and very light purple (almost white). For convenience these groups have been reduced to two in the presentation of data, the purple group including all beans which do not arouse surprise when cut, and the light group, those which markedly do. Though leaving much to be desired such a classification appears justified provided the observations are all undertaken by the same person.

Degrees of intensity of axil spot were also recorded, but for simplification only presence or absence are here recorded.

Certain batches of seedlings were seriously affected by damping off before axil spot determinations could be made. The disease was controlled in later plantings by the use of Cheshunt Mixture. Seedlings of I.C.S. 5, 9 and 86 showed marked lack of vigour, those of I.C.S. 1 and 83 the reverse.

Experimental Results.

Confirmation of Harland and Frecheville's Hypothesis.

Table V shows the record of axil spot determinations from the self-fertilized progeny of five self-compatible trees and of Imperial College Selection 100, which though classified as self-incompatible, did in fact yield one pod as a result of self-fertilization.

It will be seen that the three trees with yellow pods and no axil spot breed true to absence of spot when self-fertilized; the three trees with spot present, the red pod trees, segregate into a clear 3 : 1 ratio of spot present to spot absent. The 9 : 7 and 1 : 0 ratios do not occur in the self-fertilized progeny of these three red pod trees. No self-fertilized progeny of the remaining 12 trees could be obtained, but the evidence is sufficient to support and confirm Harland and Frecheville's hypothesis.

Application of Harland and Frecheville's Hypothesis to determine the incidence of Cross-Pollination.

The fact that yellow pod trees give seedling progeny with no axil spot if self-fertilized supplies a most useful basis for determining the degree of cross-pollination. All that is required is to grow the seed from each pod from the yellow pod types and examine for the presence of axil spot. If even one seedling from a yellow pod has axil spot, then that pod must have arisen from fertilization by some foreign pollen. But there is always the possibility that progeny with no spot might have been the result of cross-fertilization with another yellow pod type lacking the complementary factor necessary to produce spot. This point seems to have been overlooked by Harland and Frecheville when they estimated the degree of cross-pollination.

Table V.

Tree.	Pod Colour.	Selfed Pod Number.	Seedling Offspring Spot Present.	Spot Absent.	Ratio.
I.C.S. 6	Yellow	Total of 7 pods	0	264	0 : 1
I.C.S.100	Yellow	1	0	20	0 : 1
V14	Yellow	Total of 22 pods	0	737	0 : 1
I.C.S. 1	Red	1	18	4	
		2	19	12	
		3	31	9	
		4	19	12	
		5	21	11	
		6	20	8	
		7	21	6	
		8	22	11	
		9	25	4	
		10	23	8	
		Total	219	85	
		Expected	228	76	3 : 1
I.C.S. 7	Red	1	25	7	
		2	34	9	
		3	23	10	
		4	22	12	
		5	22	12	
		6	27	7	
		7	20	7	
		8	27	8	
		9	24	8	
		10	22	5	
		11	19	12	
		12	25	5	
		13	27	10	
		14	20	7	
		Total	337	119	
		Expected	342	114	3 : 1
I.C.S. 9	Red	1	13	10	
		2	25	7	
		3	18	8	
		4	16	6	
		5	22	4	
		6	18	6	
		7	11	3	
		8	20	5	
		9	11	5	
		10	21	8	
		11	20	8	
		12	24	7	
		13	34	5	
		14	20	7	
		15	19	7	
		16	17	5	
		17	18	5	
		18	19	10	
		Total	346	116	
		Expected	346	116	3 : 1

The trees under examination included eight yellow pod types. From these a total of 608 pod progenies, resulting from open pollination, were grown. Four hundred and nineteen of them displayed varying proportions of axil spot and must, therefore, have been the result of cross-fertilization. The remaining 189 pod progenies may have been self-fertilized or crossed with other yellow pod types.

Table VI.

Pod Progenies. Yellow Pod Trees.

Tree.	Pod progenies with no spot. May be self- or cross-fertilized.	Pod progenies with spot. Must be cross-fertilized.
I.C.S. 20	28	65
I.C.S. 97	33	69
I.C.S. 4	31	101
I.C.S. 94	46	94
I.C.S. 90	2	188
I.C.S. 100	19	44
I.C.S. 6	18	18
V14	12	10

Table VI shows the results from each of these eight trees. It is interesting to notice that there is a higher proportion of progeny with no spot from I.C.S. 6 and V14 both of which are self-compatible. If there were less than 15 seedlings in any one pod progeny, such have not been included in the table unless axil spot was present.

A very much higher degree of cross-pollination than Harland and Frecheville's 30 per cent. is indicated.

Another method of estimating the degree of cross-pollination from the material under examination is by direct comparison of axil spot ratios from the selfed and open pollinated pod progenies of the three red pod types, I.C.S. 1, 7 and 9. Unfortunately, there is the natural variation around the 3:1 ratio which does not permit such a critical conclusion as the 0 : 1 ratio on which were based the conclusions from the yellow pod types. In spite of this, it will be noticed from Table VII, that, as would be expected, the majority of self-fertilized progenies from these three trees fall within the groups .66-.75 and .76-.85 corresponding to a 3 : 1 ratio. When compared with open pollinated progeny the two groups contain the following number :—

I.C.S. 1, 7 and 9.—Self-fertilized 32 out of 42 or **76** per cent. falling within the two groups.
Open pollinated 72 out of 166 or **43** per cent. falling within the two groups

An indication of cross-pollination having occurred in the open pollinated progeny of these three self-compatible trees is, therefore, given.

Table VII shows in detail the frequency of the varying proportions of spot to no spot among the progeny of all the 18 trees. If self-fertilization, or cross-fertilization by a single male parent were the rule, the progeny of each tree would be grouped somewhat closely around the appropriate

Table VII.

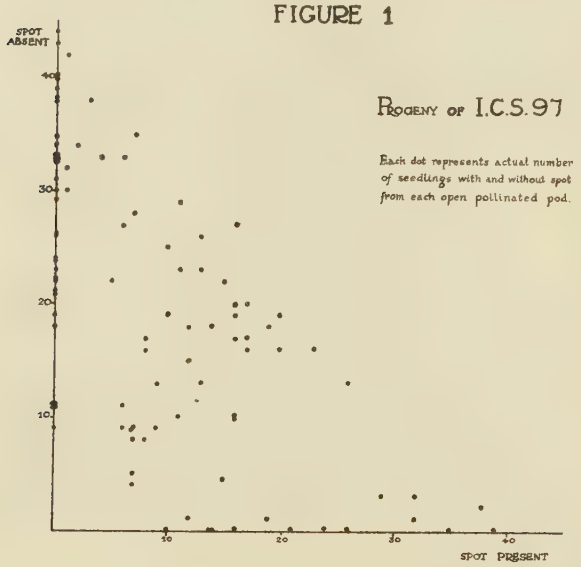
Ratio of Spot Present to Spot Absent.

Open Pollinated Pod Progenies and Certain Self-Pollinated Pod Progenies.

Tree.	0.00	.01-.05	.06-.15	.16-.25	.26-.35	.36-.45	.46-.55	.56-.65	.66-.75	.76-.85	.86-.95	.96-.99	1.00	Remarks.
I.C.S. 1 Open	0	0	0	0	0	9	15	10	20	16	4	1	0	
Self	0	0	0	0	0	0	1	2	3	3	1	0	0	
I.C.S. 9 Open	0	0	0	0	0	8	9	12	14	10	6	1	0	
Self	0	0	0	0	0	0	0	2	8	7	1	0	0	
I.C.S. 7 Open	0	0	0	0	0	2	7	2	7	5	6	0	2	
Self	0	0	0	0	0	0	0	3	5	6	0	0	0	
I.C.S. 6 Open	18	1	2	2	2	5	5	0	0	0	1	0	0	Yellow Pod
Self	7	0	0	0	0	0	0	0	0	0	0	0	0	
V14 Open	12	0	2	0	3	2	1	1	1	0	0	0	0	Yellow Pod
Self	22	0	0	0	0	0	0	0	0	0	0	0	0	
I.C.S. 100 Open	19	2	2	5	6	7	2	2	0	1	4	0	0	Yellow Pod
Self	1	0	0	0	0	0	0	0	0	0	0	0	0	
I.C.S. 86 Open	0	0	0	1	7	5	12	4	4	0	0	0	0	
I.C.S. 17 Open	0	0	0	0	0	1	4	2	3	5	3	0	1	
I.C.S. 83 Open	0	0	0	0	2	14	21	17	23	9	5	1	3	
I.C.S. 5 Open	0	0	0	0	0	1	5	7	6	12	1	0	3	
I.C.S. 3 Open	0	0	0	0	1	3	17	3	8	5	2	0	1	
I.C.S. 99 Open	0	0	0	1	2	2	5	3	1	2	1	2	1	
I.C.S. 2 Open	0	0	0	0	1	2	4	4	2	1	1	0	0	
I.C.S. 94 Open	46	4	5	9	7	13	13	5	4	2	2	0	3	
I.C.S. 20 Open	28	3	10	3	8	13	7	5	1	2	2	0	4	
I.C.S. 4 Open	31	3	3	11	9	15	8	8	5	6	0	2	7	Yellow Pod
I.C.S. 97 Open	33	6	3	4	8	10	13	5	2	0	4	1	6	
I.C.S. 90 Open	2	2	0	1	2	2	5	2	2	0	0	0	0	

ratio. The general dispersion, however, leads to the conclusion that considerable cross-pollination has taken place, and that more than one male parent has been responsible. It would appear that not only do a number of flowers, later resulting in pods, become fertilized by pollen from different trees, but also that any one flower might be fertilized by mixed pollen from several trees. This would explain the ratios which occur and cannot be considered significant for any of those mentioned earlier in this paper. The general dispersion can be made a little more clear by recording in graph form all the axil spot determinations of the progeny of one tree I.C.S. 97.

FIGURE 1



Examination of Bean Colour.

A check on the conclusions drawn from the axil spot determinations was made by recording the bean colour. Unfortunately, only four trees produced obvious variation of bean colour within certain pods, and of these only one, V14, a yellow pod type, was self-compatible. This tree, however, supplied excellent material for tracing the incidence of cross-pollination. Beans from self-fertilized pods segregated clearly into a 3 : 1 ratio as follows :—

Total of 22 self-fertilized pods produced :—
Purple beans 729, Light coloured beans 238.

Using this knowledge, and relying on axil spot determinations a self-fertilized pod from this tree must fulfil two conditions :—

(*a*) All the seedlings must be without spot.

(*b*) The beans must be significant for a ratio of 3 purple beans to one light coloured bean.

Twenty-two open pollinated pod progenies were examined, but only nine fulfilled both conditions for self-fertilization. The open pollinated and self-fertilized progeny of this tree are of sufficient interest to record fully, and this is done in Table VIII.

The three other trees, sometimes throwing pods with a proportion of light coloured beans, were self-incompatible. Results are given in Table IX.

Table VIII.

Self and Open Pollinated Progeny of VI4.

Self Pollinated.						Open Pollinated.					
Pod number.	Purple beans.	Light beans.	Significant 3 : 1 Significant 0 : 1	Spot present.	Spot absent.	Pod Number.	Purple beans.	Light beans.	Significant 3 : 1 Significant 0 : 1	Spot present.	Spot absent.
1	31	9	√√	0	29	1	29	11	√×	13	7
2	30	12	√√	0	23	2	32	0	××	13	16
3	23	8	√√	0	27	3	33	14	√√	0	26
4	33	12	√√	0	35	4	27	7	√√	0	24
5	35	11	√√	0	32	5	42	1	××	11	24
6	33	12	√√	0	36	6	20	16	×√	0	27
7	40	8	√√	0	36	7	25	13	√√	0	16
8	28	15	√√	0	36	8	43	0	××	16	15
9	43	5	×√	0	38	9	33	12	√√	0	30
10	34	12	√√	0	26	10	34	9	√×	2	31
11	36	9	√√	0	37	11	30	10	√√	0	30
12	34	11	√√	0	37	12	38	0	××	11	25
13	33	8	√√	0	24	13	31	10	√√	0	25
14	29	7	√√	0	18	14	27	7	√×	3	26
15	37	10	√√	0	36	15	29	16	√√	0	27
16	38	12	√√	0	45	16	26	14	√√	0	16
17	33	14	√√	0	42	17	33	0	××	8	11
18	31	12	√√	0	40	18	42	1	×√	0	31
19	31	15	√√	0	42	19	18	3	√×	4	9
20	36	9	√√	0	34	20	15	15	×√	0	24
21	29	16	√√	0	34	21	30	9	√√	0	18
22	27	11	√√	0	30	22	32	2	××	16	8

Table IX.

Tree.	Pods with only purple beans.	Pods with some light beans.
I.C.S. 94	100	63
I.C.S. 86	22	27
I.C.S. 4	103	34

The interpretation of these figures is limited to the conclusion that pollination involving more than one male parent has taken place.

Discussion.

It is necessary to allude to self-incompatibility, since the incidence of this phenomenon implies cross-pollination, if a crop is produced. The writer's investigations into self-incompatibility—published in this and in the preceding report—indicate that no change to a self-compatible state takes place, and he has been unable to confirm Pound's findings. Pound (3) states as follows :—"Either these heavy bearing trees normally set all their fruit from cross-pollination, or else they were only temporarily self-incompatible. The first assumption seemed most improbable in view of the general inefficiency of cross-pollinating agents, and steps were taken to check the second by hand-pollinations made from time to time." Unfortunately, no figures were given of the results of those hand pollinations. Basing his conclusions on the assumed change to the self-compatible state, during which the crop was set, Pound (3) states that, "The evidence now suggests that the bulk of the Trinidad cacao crop is produced as a result of self-pollination on all trees . . ." The writer hopes to have produced figures to show that the contrary is the truth, and even if cross-pollinating agents are inefficient that they are sufficient to cause a very high percentage of cross-fertilization amounting to about about 50 per cent. with self-compatible trees, and that there is ample justification for assuming all the pods on self-incompatible trees to be the result of cross-fertilization.

But the immediate importance of the conclusions now drawn is in the choice of parent trees to supply material for planting. If seed is taken from self-incompatible trees the male parentage is unknown and may well be of inferior quality. Cheesman and Pound (4) state that, "Our selections are very thinly scattered in the fields, and as a rule the individual is bearing at least four or five times the crop of any neighbouring tree." If the seed from the selected trees were cross-pollinated, it would appear that the male parentage would indeed be inferior. It will therefore be hardly surprising if seed, taken from such selections, produces plants which will fall short of the female parental performance.

There is nothing novel in this statement. As long ago as 1900, Hinchley Hart (5) wrote as follows, "Seed should also be taken from trees situated at a distance from inferior varieties, for the purpose of avoiding as far as possible the variation which will naturally occur, where cross-fertilization is free to take place, for if poor varieties are near to the seed trees the latter will most certainly produce a variety having some of the characters of the poorer kinds blended with its own." Again, "When selecting pod for seed, it is at once clear, that if taken from the open field, only the maternal parent of the seeds contained therein, can be known". In 1908, Hamel Smith (6) wrote in his book, "The Future of Cacao," the following :—"These 25 trees (Criollo) are situated in St. Lucia, and exposed as they are to the influence of cross-fertilization from inferior varieties, seedlings from them would soon degenerate to a Forastero type." The surprising fact is that, although these two authors were considered recognized authorities on cacao, no one since then has paid serious attention to the male parentage of seed used for distribution. But whereas these authors based their advice on the conjecture that a high degree of cross-pollination took place, the writer replaces conjecture by facts and leaves unaltered the advice. Where propagation by seed is desired, the importance of the selection of the female is obvious, but the equally important male has been completely neglected.

A point, which mainly concerns the experimentalist, also arises. If progeny trials of selected mother trees are laid down with open pollinated seed there is the possibility that unreliable conclusions will be drawn, especially if the mother trees are self-incompatible. Thus, in laying down seedling progeny trials, often only a few pods from each of the selected mother trees are required to supply the necessary number of seedlings. If these seedlings turn out well, the experimentalist might be led to conclude that other seed taken from the same mother tree would produce plants of a similar performance. As has been shown in this paper, the chances are that the male parent or male parents may well be different from those which fertilized the seed used in his trial, and consequently the performance of the offspring will be different. As an example, if I.C.S. 4 were the mother tree, the progeny of which it was desired to test, three pods would supply 100 seedlings which would be a reasonable population. These three pods might easily be taken from those of the 31 (*see* Table VI) which yielded seedlings with no axil spot. When these 100 seedlings reach maturity, they will bear only yellow pods, and the experimentalist might be tempted to conclude that, in distributing seed from mother tree I.C.S. 4, he was distributing seedlings all of which would mature into yellow pod types. Some acrimony might result when reports of red pod types from other growers using seedlings of I.C.S. 4 came to hand, and such red pod types certainly would occur. What is true of one set of factors controlled genetically is true of others; and the improvements expected from selection, as long as propagation by seed is employed, are based on genetics.

Summary.

1. Harland and Frecheville's hypothesis regarding the genetics of axil spot was confirmed.

2. Their methods were applied to determine the amount of cross-pollination among 18 River Estate trees.

3. Where possible the results were checked by an examination of bean colour.

4. A very high degree of cross-pollination was indicated. For self-compatible trees up to 50 per cent. of pods were cross-fertilized. A higher percentage was proved for self-incompatible trees, but the method did not allow conclusive proof that all pods on such trees were the result of cross-fertilization.

5. The varying ratios of spot present to spot absent in pod progenies of individual trees suggested fertilization of different flowers by different male parents, and the absence of significant ratios in some progenies suggested pollination by mixed pollen.

6. The importance of frequent cross-pollination—probably by inferior male parents—was stressed in relation to seedling planting material.

References.

1. Harland, S. C. and Frecheville, G. E.—Natural Crossing and the Genetics of Axil Spot in Cacao. *Genetica*, 9 (1927), 279-88.

2. Wellensiek, S. J.—De Erfelijkheid van Zaadlobkleur bij Cacao als Basis voor Qualiteitsselectie. *Arch. Koffiec. Ned.-Ind.* 1931 :5 : 217-33.

3. Pound, F. J.—Studies of Fruitfulness in Cacao. V. Conditional Self-Compatibility and its Implications. *Fourth Annual Report on Cacao Research*, 1934.

4. Cheesman, E. E. and Pound, F. J.—Further Notes on Criteria of Selection in Cacao. *Third Annual Report on Cacao Research*, 1933.

5. Hart, J. H.—Cacao, 1900.

6. Hamel-Smith, H.—The Future of Cacao. 1908.

SOME FACTORS CONTROLLING THE YIELD OF YOUNG CACAO.—I.

O. J. Voelcker and F. W. Cope.

In common with other observers, the writers have been impressed by the tree to tree variation in yield between cacao trees of similar age and vigour. Thus, in a row of seedling trees of equal age and of apparently uniform size and health, several will be noticed carrying numerous cherelles, others a few and others again without a single fruit. The object of the investigations recorded in this and a subsequent paper is to attempt to assess the factors responsible for the variation in yield between such trees.

Material Available.

A block of cacao trees at River Estate had been planted some years previously with open pollinated seed of six Imperial College Selections. Some trees in this block had commenced to bear in 1936. The following details have been supplied through the courtesy of the Trinidad Department of Agriculture.

The whole block of 12 acres comprises a variety trial of the six selected mother trees; superimposed is a manurial experiment and superimposed again is a cultivation trial. The block is subdivided into 36 plots, each containing 99 stands at a spacing of 12 feet by 12 feet. The trees in each plot were planted from the open pollinated seedlings of one of the six selected trees. As it was impossible to carry out detailed observations on the trees of all 36 plots, six were chosen from the south border of the block.

Figure 2 shows the lay-out of one plot.

The six plots are shown on page 15.

The artificial manures were first applied in 1936. In the mulched plots 3 and 5, the soil dug from the deep drains was used to cover the mulch.

History of the Six Plots.

The land was previously under mature cacao which was cut down (but not burnt) prior to establishing temporary shade of tannias, cassava and bananas, and permanent shade of immortel.

The soil of the six plots is generally considered to represent the average of soils on which cacao is grown at River Estate, thereby implying a freely draining and rather gravelly soil, significantly lacking in potassium.

Seed from the six selected female parent trees was planted in adjacent nurseries early in 1933 and planted out in June of the same year by the "pylon" method. Each tree received pen manure and urine and has subsequently received very considerable attention. Supplying has been necessary to the extent of only five per cent. though considerable damage has at times been caused by cacao beetles and by thrips. Plot V has suffered from lack of temporary shade and all six plots tend to deteriorate on their northern sides. Plot I, for no apparent reason, contains trees larger than those of other plots. Judged on general appearances, the trees are in satisfactory condition and are probably better than would have been found in average young fields in Trinidad. Spraying with Bordeaux Mixture against thrips (*Selenothrips rubrocinctus* Giard) was carried out in November-December, 1936, June and December, 1937.

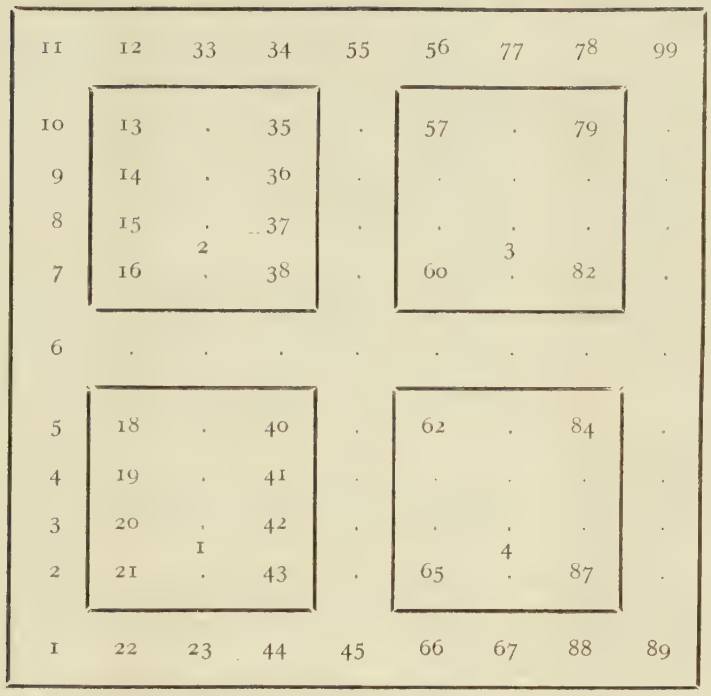


FIG. 2.

Each plot has 99 stands and is divided into four sub-plots, each of 12 stands and each receiving different manurial and cultivation treatments.

Plot	Female parent.	Male parent.	Manurial Treatment Given 1.5 lb. per Tree.				Cultivation treatment of whole plot.
			Sub-plot 1	Sub-plot 2	Sub-plot 3	Sub-plot 4	
1	I.C.S. 100	Unknown	K	K+P	P	Control	Deep drains, round ridging.
2	I.C.S. 6	,,	Control	P	K+P	K	Normal.
3	I.C.S. 4	,,	K+P	P	K	Control	Mulch, deep drains, round ridging.
4	I.C.S. 5	,,	K+P	K	Control	P	Normal.
5	I.C.S. 1	,,	K	P	K+P	Control	Mulch, deep drains, round ridging.
6	I C.S. 2	,,	Control	K	K+P	P	Deep drains, round ridging.

A Consideration of Factors Influencing Yield.

It may be advisable to stress the three main stages by which yield becomes possible :—

(1) FLOWERING .—Unless flowers are produced yield is manifestly impossible.

(2) SETTING.—It is now known that unless the flowers are suitably fertilized, cherelles cannot result from them.

(3) CHERELLE MATURATION.—If, for any reason, the young cherelles cannot reach maturity, no ripe pods can be harvested.

No apology is given for re-stating these axioms.

Any other factor influencing yield can only do so through its effect upon one or more of these vital stages. The authors have, therefore, deemed it necessary to record for each tree as accurately as possible the intensity of flowering, the degree of cherelle setting and the number of losses occurring between setting and harvest : and further, have considered it desirable to establish whether there is or is not any correlation between self-compatibility and high yield. Provided that the quantities of flowers and the losses after setting are similar for both self-compatible and self-incompatible trees, any superior ease with which self-compatible trees

set their fruit would at once result in higher yields from the self-compatible tree as compared with the self-incompatible trees.

Detailed tree records would also show at what stage the fertilisers acted with maximal effect.

The authors hope in time, therefore, to be able to say for any individual tree, "This tree produced so many flowers, so many cherelles and so many ripe pods during the one (or two) years of observation. The tree is, or is not, self-compatible and has received such and such artificial manure." By comparing trees, receiving similar treatment, in their reaction to self-pollination they hope to gain valuable information.

Observations Recorded.

(1) Flowering.—The actual number of open flowers is counted on each tree at fortnightly intervals. Counts over the whole trees are only made possible by their small stature, affording the observer a clear view of the highest flowering branches. Previous work has shown that about 80 per cent. of unpollinated flowers fall on the day following opening, the last 20 per cent. on the next day. Hence a count on any one day will include 20 per cent. of the previous day's flowers. To obviate this error the estimated flower production over the whole fortnight has been obtained by multiplying the fortnightly count not by fourteen, but by ten. It may here be mentioned that the tree to tree variation in flower production is so great as to warrant of little importance the inevitable minor errors.

In flower counts recorded by other authors the trees under observation have been mature and the flowers on only one branch or even only a portion of a branch have been counted. This method of sampling is probably not a very good index of the tree as a whole, and it is noteworthy that Pound, working on mature trees, omitted flower counts altogether.

(2) Setting.—In order to simplify the procedure in obtaining information on the intensity of setting, only those cherelles which have reached an age of from four to six weeks are recorded. There is, therefore, a considerable gap in the observations between flowering and its relevant setting (as defined above) but again other work has supplied indications on which this gap might be filled; that is, by considering as set a fixed multiple of the 4-6 week old cherelles actually counted, and there would therefore be no advantage gained in using the "number of flowers set" instead of the "precise cherelle count". In the chain of observations from flowering to harvest, this gap is regretted but must be considered inevitable under the conditions of the practice adopted.

At each fortnightly flower count, cherelles at the indicated stage of development are marked by a loop of fine copper wire loosely fitted round the cherelle stalk. New cherelles, and any possibly overlooked on the previous occasion, are thus marked and counted. Wilted fruits are pulled off, their numbers recorded, and the wire made ready for use again. The risk of counting as new any cherelle twice is obviated by this method of wiring. If cherelles less than four weeks old are marked with wire there is the possibility that, on wilting, the cherelle and wire will fall instead of remaining on the tree till the next count.

The records for each tree are kept on a single page of a note book, which allows easy checking of cherelles and pods, since the number on the tree at any time should equal the difference between the total of all new cherelles and the sum of wilted cherelles and pods harvested since the commencement of the observations.

(3) Harvesting. —At each fortnightly round, a record is made of the number of mature pods harvested. As a result of testing each tree for self-compatibility (*see* below) certain of the mature pods are the result of hand-pollinations and such pods are recorded separately.

Trunk Circumference.

This measurement was taken for each tree as being the most easily obtained index of a tree's size. The influence of general vigour on yield, given by this measure, can be ascertained.

Testing for Self-Incompatibility.

The authors considered that self-incompatibility might be a depressing factor in determining yield and they wished, therefore, to classify each tree on its ability or inability to set with its own pollen. Hand-pollinations were therefore resorted to.

Two boys were trained to take the fortnightly flower and cherelle counts and when not so employed were given instruction in the technique of pollination. Having gained some proficiency in the method, they hand self-pollinated up to twenty flowers per tree. Usually three days later the numbers remaining on and the numbers fallen were recorded, and at 14 days after pollination a further count was made. To ensure that the work of pollination was properly carried out, one of the authors almost always worked with the boys, all three finishing the requisite number of hand-pollinations before proceeding to the next tree. Each individual marked the flowers he had pollinated with his own coloured wool; one boy used red wool all the time, the other white wool while the writers used blue wool. At the count taken three days after pollination any inefficient work by a member was shown up by the other two. All the flowering trees in one plot were tested before passing to another. The six plots were taken in rotation and when the whole block had been tested, a new set of pollinations was undertaken.

It at once became evident that some trees which failed to set at the first test would do so at a subsequent test, and *vice versa*. Observations suggested that, though this was in some degree due to faulty pollination, the climatic conditions at the time of pollination were of considerable effect in determining the amount of setting. On some mornings pollen would be so abundant that only one stamen from each flower was sufficient to ensure adequate pollen being placed on the stigma, and on others, a definite scarcity of pollen made the operation tedious and a little unreliable. A considerable tree to tree variation in the amount of pollen produced, on any one morning, induced the authors to reduce the number of flowers pollinated per tree from twenty to ten to allow a larger number of repetitions at different periods.

Before any attempt was made to classify the trees according to self-compatibility, or self-incompatibility, consideraion was given to the following points.

(*a*) The flowers which were self-pollinated by hand were unguarded and hence a few might have set by cross-pollination where normally no setting would or could take place.

(*b*) More weight was given to a positive result of self-pollination than to a negative result and more importance was accorded to results from ten pollinations than to those from only a very few. This requires amplification; certain trees flowered only very sparsely and a few hand-pollinations could be made at any one test. Thus, a tree giving five cherelles at a fortnight from ten pollinations would be classified as self-compatible, but not necessarily so a tree which set one fruit from two pollinations. The latter tree would be tested again.

(*c*) It was also borne in mind that certain incompatible trees might produce a very few cherelles from self-pollination, and that there is the possibility of varying degrees of self-incompatibility.

Typical examples from the records are given to show the lines on which classification was made, and are from plot 3E.

(*a*) Classified as Self-Compatible.

Tree.	13		30		53		74		80	
	Poll.	Set	Poll.	Set	Poll.	Set	Poll.	Set	Poll.	Set
1st test	6	0	15	10	10	3	25	9	16	7
2nd test	4	2	14	0	15	3	15	10	15	3
3rd test	4	0	6	2	14	5	15	0	8	4
4th test	6	3	2	0	11	1	10	4	10	1
5th test	12	6	10	5	10	6	10	6	10	6
6th test	6	1			2	0	10	7	10	9

(*b*) Classified as Self-Incompatible.

Tree.	2		4		5		22		55	
	Poll.	Set	Poll.	Set	Poll.	Set	Poll.	Set	Poll.	Set
1st test	10	0	15	0	6	0	4	0	13	0
2nd test	9	0	10	0	10	0	10	0	4	0
3rd test	6	1	8	0	7	0	4	0	10	0
4th test	10	0	3	0	10	0	10	1	10	0
5th test									10	0

(*c*) Classified as, at present, doubtful.*

Tree.	17		26		27		
	Poll.	Set	Poll.	Set	Poll.	Set	
1st test	4	2	13	0	15	1	
2nd test	1	0	15	1	15	1	And all trees which have not yet flowered.
3rd test	1	0	11	0	1	0	
4th test	1	0	4	1	10	0	
5th test			4	1	10	6	
6th test			3	0	3	0	

* In most cases these doubtful trees have flowered only sparsely so that really conclusive tests upon them have not been possible.

Results.

Although at least one year must elapse, since the commencement of the observations, before any detailed analysis can be presented, certain figures are now available to indicate the influence of incompatibility upon the numbers of cherelles produced. *See* Table X.

The general conclusions which may be drawn are:—

(1) In every case, the self-compatible tree sets a far higher percentage of cherelles than the self-incompatible tree, sometimes over five times as much (Plot 2[1]).

(2) On the whole, the incidence of cherelle wilt is rather more severe in the self-compatible tree than in the self-incompatible tree, although this difference only very slightly militates against the much greater bearing of the self-compatible tree.

(3) Flower production is much the same for both classes of tree.

Table X.

BEHAVIOUR OF YOUNG CACAO TREES, COMPARED ON A BASIS OF PRESENCE OR ABSENCE OF SELF-COMPATIBILITY.

1. The figures given below indicate the number of cherelles set (6 weeks old) per 10,000 flowers borne on trees of the two classes respectively.

	Plot 1A.		Plot 2D.		Plot 3E.		Plot 4B.		Plot 5F.		Plot 6C.	
	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.
Control	124	26	413	—	178	23	58	35	117	13	313	209
K	175	24	237	50	147	39	161	14	144	19	100	34
P	115	53	88	30	136	41	218	77	161	—	292	24
K-P....	124	44	339	38	150	55	171	40	105	17	24	9
Guard rows	165	29	224	64	151	35	144	22	100	25	148	35
Average	141	35	260	46	152	39	150	38	125	24	175	66

2. The figures given below indicate the percentage of the above cherelles which are lost as a result of cherelle wilt.

	Plot 1A.		Plot 2D.		Plot 3E.		Plot 4B.		Plot 5F.		Plot 6C.	
	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.	Self-Com.	Self-Incom.
Control	47.6	36.8	61.4	—	46.4	11.8	16.0	42.8	43.1	29.4	42.8	49.0
K	26.8	25.6	31.3	—	36.0	18.3	48.7	50.0	36.9	40.5	27.3	36.8
P	52.8	29.2	30.3	33.3	38.1	38.2	38.8	15.6	45.5	—	58.7	53.6
K-P....	38.2	35.0	61.4	62.5	17.0	27.2	50.7	24.5	42.2	42.8	—	—
Guard rows	43.0	29.0	30.7	24.8	40.7	39.2	47.0	34.0	29.4	17.6	18.7	7.5
Average	41.7	31.1	43.0	40.2	35.6	26.9	40.2	33.4	39.4	32.6	36.9	36.7

3. Over the period of time for which the experiment has been run (20.7.37-28.2.38) the floral production of each type of tree has been, on the average

	Plot 1A.	Plot 2D.	Plot 3E.	Plot 4B.	Plot 5F.	Plot 6C.	Average.
Self-compatible	2,900	1,550	3,310	2,450	2,080	1,850	2,357
Self-incompatible	4,280	1,260	3,170	2,150	2,230	1,110	2,367

STUDENT INVESTIGATION 1936-37.

INCOMPATIBILITY AND POLLINATION IN CACAO.

Summary of Dissertation Submitted.

By A. F. Posnette.

This paper is divided into two portions; the first deals with pollen incompatibility, and the second with the natural pollination of cacao. Both are prefaced by a general introduction which stresses the importance of avoiding the widespread establishment of clonal blocks of self-incompatible selections, without further knowledge of the agents of cross-pollination, and with much still to be learnt about the causes of failure resulting from incompatible matings.

It was pointed out that the failure to "set" in such incompatible matings might be due to one of the following causes:—

1. Inability of the pollen grains to germinate.
2. Too slow growth of the pollen tube.
3. Failure of the gametes to fertilize the ovum.
4. Failure of the male and female nuclei to merge within the cytoplasm of the ovum.
5. Subsequent action of lethal factors.

All of these possibilities are fundamentally genetic, and the experiments carried out were concentrated on the first two. Of a row of five trees tested for incompatibility, four were found to be self-compatible and one self-incompatible. A further self-incompatible tree was also chosen to supply material for pollen growth tests.

Pollen Germination and Pollen Tube Growth.

No difference was noted between the germination of pollen grains when taken from self-incompatible trees or from self-compatible trees. The germination tests were made on the stigmata of flowers from which the pollen was taken. Similarly no structural or staining differences could be noted in the styles or stigmatic lobes of flowers taken from either of the two types of trees.

An examination of self-pollinated compatible and incompatible flowers three hours after pollination showed no differences. Pollen tubes could be traced entering the stigmatic lobes in both. Six hours after pollination two types of pollen tubes were noted, each type being represented in the compatible and in the incompatible grains. In one type, the grains and tubes freely took up the cotton blue stain, in the other they were clear. The suggestion was made that the clear grains and tubes had already passed their contents down the style, and there was some evidence to show a preponderance of these clear grains and tubes in the compatible pollen. Owing to the difficulty of tracing the pollen tubes down the style resort was had to sectioning. Mucilage and torn tissue, inevitable with such delicate material, prevented a very clear observation of tube growth. In one compatible pollination, however, a tube was observed entering the ovary. The incompatible pollinations showed distinctly a number of short darkly stained tubes ending abruptly in an inflated tip and sometimes growing away from the ovary and up the style. No conclusion was drawn that incompatible pollen tubes cannot reach the ovary.

In order to allow a longer interval of time for the pollen tubes in incompatible matings to grow, 20 pollinations were made in the bud. This did not result in any increased stimulus. Again, in order to avoid the difficulties which incompatible tubes might experience in passing down the style, a number of pollinations was made at the base of the style. There was no subsequent difference in behaviour between this and the usual stigmatic lobe method of pollination.

Cross-Pollination with *Th. angustifolia* and *Th. bicolor*.

It was thought that some useful information on incompatibility might be obtained by studying the effect of pollination with related but distinct species. Interspecific crosses would probably fail to set fruit because of different chromosome numbers or because of nuclear complications following fertilization. Pollen from *Th. angustifolia* was easily obtained over the very short period during which a tree of that species was flowering. Although *Th. bicolor* produced an ample supply of flowers, the pollen was very scanty. Crosses with *Th. angustifolia* pollen onto flowers of self-compatible trees caused a delay in flower abscission in all respects similar to incompatible self-pollinations. Crosses with *Th. bicolor* failed to cause any delay in abscission, and microscopic examination suggested that the pollen grains of *Th. bicolor* did not germinate on the stigmata of self-compatible *Th. cacao* trees. The conclusion was drawn that the initial pistil growth noted in the interspecific cross (*Th. cacao* x *Th. angustifolia*) and in self-incompatible pollinations was due to pollen tube stimulation. Similar stimulation was noted in flowers from witchbroom infected cushions.

Natural Pollination.

An experiment was designed to identify the class of insect responsible for pollination. Six self-compatible young trees were chosen. Two were used as controls; two were completely encaged in fine cloth after the removal of all insects by spraying; two were isolated from crawling insects except from a species of very large ant, by sticky bands round the trunks

after a preliminary spraying. Observations were recorded on the number of flowers opening and on the number pollinated. Pollination was judged to have occurred if the ovary was slightly swollen and the stigma withered. The records were commenced early in February and terminated in the first week of May, 1937.

	per cent. pollinated.
2 control trees unguarded ...	5.2
2 banded trees	1.3
2 caged trees	0.2

These figures are abstracted from counts from each individual tree, but between trees there was a great variation in flower production. The curves of setting—flowers pollinated—did not always follow the curves of flowering.

It was found that pollination at the base of the style could result in setting, and that the pollen need not necessarily be placed on the stigmatic lobes. Five hand-pollinations at 3.30 p.m. on flowers opened the same morning resulted in cherelles, but out of 10 hand-pollinations at 9.0 p.m. only two set. Thus a flower would appear to be capable of setting with its own pollen from the time of anthesis to late in the afternoon of the same day.

From the results of setting on the cage, banded and control trees and from general observation, Posnette concludes that " The most likely agents of pollination over the period of the investigation (February to May) are nocturnal ants, helped by smaller ants, and by Drosophilids in rainy weather".

O.J.V.

CACAO.

A Summary of Literature Since 1931.

By O. J. Voelcker.

During the past seven years there have been important contributions to our general knowledge of cacao, and the present summary is designed to bring together the more outstanding data that have been published. This summary follows naturally the " Economic Botany of Cacao " (3) which, in turn, surveyed the literature to the end of 1930.

In the British Empire, the period 1931-37 saw the commencement of a planned scheme of cacao research at the Imperial College of Tropical Agriculture, Trinidad, designed, not only to supply selected planting material, but also to elucidate fundamental problems connected with the crop. In Nigeria, in spite of the expanding and apparently flourishing nature of the cacao industry—scarcely checked by the phenomenally low prices obtained—a far sighted policy with regard to cacao improvement was quietly initiated. Outside the Empire, several important investigations have been carried out by the Dutch in Java.

Scope.

The immediate object of research on cacao is to increase the profits to the planter, whether he be the owner of one or a thousand acres. The factors bearing on profit are numerous, and for the purposes of this summary special attention has been paid to the question of planting material and to certain physiological phenomena that may limit yield. Hence, only brief mention will be made of the literature concerning the relationship of soil types, manurial experiments, incidence of diseases and cultural practices to the behaviour of cacao trees.

Selection.

In no country in the world has any one yet supplied for distribution cacao planting material of guaranteed ability. Perhaps the nearest approach to this desirable state comes from West Africa (excluding the Cameroons) where the variety grown, *Theobroma leiocarpa* Bern., most closely represents the " pure line " of plant breeders, but even within this variety considerable variability has been shown to exist. The cacao fields of Bahia in Brazil are also thought to be populated with trees of marked uniformity (2). In Trinidad, Ceylon, Java and the former German Cameroons considerable variation between trees in type, yield and quality of the beans has been noted; to reproduce the potentialities of yield or quality of only the best of these is the ultimate object of selection.

Consciously or subconsciously selection has been practised for many years in most cacao growing countries, but the results, as recorded from the offspring, have often proved disappointing. There is, however, every reason to believe that, where, in the past, progeny of selected trees have failed to fulfil expectations, the methods of selection and of propagation have been at fault. In recent research programmes importance has, therefore, been given to the establishment of criteria for selection; to formulate these essential criteria at once necessitates work of a fundamental nature on the underlying factors which determine yield or quality.

Selection in Trinidad.

In two papers Pound (22) and Cheesman and Pound (5) lay down the criteria adopted in the choice of the Imperial College Selections. The

determination of standards was only made possible by an exhaustive study by Pound (23) of the whole range of variation within the Trinitario trees of the island. Pound (23) and Voelcker (5) have recorded the variability which occurs in the ratio "pods to weight of wet beans" according to the time of year, and both authors realized the necessity of judging a tree's performance by the weight of wet beans and not by the number of pods. Pound was able to determine reliable sampling standards, so that it would not be necessary to weigh the whole crop in wet beans. He found that for practical purposes a sample of 30 pods would be adequate to characterize the tree.

Resulting from this work, Cheesman and Pound were able to formulate standards of selection. These were as follows:—A tree worthy of selection must bear pods not more than seven of which would yield one pound of dry cacao, and the tree must be producing this cacao at a rate of not less than one ton to the acre. These two impositions guaranteed that the selected trees were bearing large sized beans, and that the yield of such beans was at least five times greater than the average of Trinidad trees. Fortunately the selection for large beans was not adverse to selection for yield; on the contrary, the heaviest yielding trees when recorded in weight of wet beans, and when allowance had been made for the space occupied by the tree, had in fact large beans. The allowance for the spread of the tree was made by calculating the number of similar trees required to fill one acre. Thus small trees, occupying little space, were often found to bear at a higher rate per acre than the outstanding giants which so temptingly catch the eye. Undoubtedly selection in the past had paid particular attention to such spectacular trees, which often produce very small beans and those practising selection had not realized that an acre of such trees would yield less cacao than was confidently expected.

These criteria of bean size and yield were wisely not followed too strictly, and some latitude was given to trees growing in exceptional localities. As far as possible every precaution was taken to guard against selecting trees which were heavy yielders owing to a particularly favourable soil or position. The selections finally made numbered one hundred—a designedly large population to allow possible discarding after the preliminary progeny trials. It was foreseen that, as research pushed deeper into fundamental factors governing yield, some of the selections might have to be abandoned for any but experimental purposes. An example of this has already occurred through the discovery that a proportion of the selected trees are self-incompatible.

No particular attention was paid to the colour of the beans produced from the selected trees, though a number of the hundred do in fact yield beans of light cross section. The pure white beans characteristic of the Criollo cacaos were not taken into consideration for two very good reasons, firstly because this selection was made to meet the demands of the Forastero market and planting community, and secondly because the selection for pure white beans requires a different set of criteria. The question of white beans is dealt with separately under "Criollo selections".

Two other points in connection with the Trinidad Forastero selection should be mentioned. The general tendency of trees to remain from season to season either good or poor yielders is generally recognized, but it was considered dangerous to rely on tree yields obtained over only one year. Thus the practice adopted was to tag 1000 trees during the 1933-34 season, such trees passing the "pod value" standard, and found on the recorded yields of that season, to be promising. Yields were again taken in the following year, and on the records of two seasons' yield accurately obtained, and often supported by the local knowledge of planters or overseers, the final selection was made. The other point concerns the great range pointed out by Hardy (14) of soil types, on which the cacao estates of Trinidad are established. It would obviously have been unwise only to select trees growing on the most fertile soils, and in practice the selected trees have been chosen to cover all the main types.

Criollo Selections.

Owing to the scarcity of trees recorded in Trinidad and in Tobago, selection has been carried out along somewhat different lines. In the first place it is difficult to determine exactly which are Criollo trees. Individuals may answer to the description as far as pod types, thinness of shell, and bean size are concerned, but the colour of the beans may be dark purple, or a mixture of white, light and dark purple. This may be due to the self-pollination of a tree heterozygous for bean colour, or to cross-pollination of a homozygous white bean tree by a purple beaned tree. In the Criollo selections the standards of yield have been judged mainly by eye, and to pass the selection standard the beans must be very large, the pod shell thin, and at least one pod containing only pure white beans. Several such trees have been selected in Tobago, and the appearance of them does not suggest any marked lack of vigour. The selection is proceeding.

Summary of Forastero Selection in Trinidad.

Criteria.

1. Not more than seven pods required to produce one pound of dry cacao.
2. Yield not less than at the rate of one ton of dry cacao per acre.

Precautions taken.

1. Allowance for pod value.
2. Allowance for tree size.
3. Yield records over not less than two seasons.
4. Selected trees on different soil types.

Population.

Trees examined 50,000.
Preliminary selection 1,000.
Final selection 100.

Selection in Nigeria.

Cacao selection was commenced as part of the programme of the Botanical section of the Department of Agriculture in 1931. A full report has been published (43), and the main items of interest are summarized below.

Yield, in pounds of dry cacao per tree, was adopted as the main criterion, though the general appearance of the trees to be selected was also taken into consideration. In comparing the criteria of selection with those of Trinidad, it will be noticed that no correction was made for tree size, and little value was placed on individual bean weight. The omission of the former might well have been of considerable importance had not the selected trees been confined to a single plot established only 19 years earlier, thereby insuring a more uniformly sized population than is to be found in the majority of Trinidad fields. The inclusion in the selected list of trees yielding small beans, as many as 528 to the pound of dry cacao, can only be justified by an exceptionally heavy yield, which does not appear to occur among all the selections. Taking 200 trees to the acre—the selected trees were growing in a plot planted 15 feet by 15 feet and scarcely formed a complete canopy—five of the 19 selected trees were yielding at the rate of 15 to 20 cwt. of dry cacao per acre, eight at the rate of 20 to 30 cwt., three at the rate of 30 to 40 cwt., two at the rate of 40 to 50 cwt., and one at 52 cwt. This particular tree actually yielded at the rate of 62 cwt., in the crop year 1933-34; the other figures apply to the average of two seasons 1932-33 and 1933-34. Thus except for certain exceptional trees the Nigerian selections are bearing at a comparable rate with those in Trinidad, but the bean size of the former is very considerably smaller.

Preliminary selection was based on yield in pods recorded over ten seasons. Forty-nine trees passed the initial standard which was an average of 70 pods per annum (1921-22 to 1930-31) or of 90 pods per annum (1925-26 to 1930-31). During the season 1931-32 the yield of these trees was recorded in weight of wet beans, and from that the weight of dry beans calculated, using the previously determined ratio of 100 lb. wet cacao equivalent to 43 lb. dry fermented cacao. Seasonal variation in the ratio "number of pods to weight of cacao" was eliminated by recording yield over the whole crop year in weight of wet beans.

It will be seen that selection in Nigeria has been limited to a very small population. Of particular interest is the remark that within this population "there is more variation than is to be found among trees growing in native farms." Consequently there appears more likelihood of segregation and possible improvement in the progeny of the selections than would have occurred if attention had been devoted to the apparently homozygous population of native farms. Hope for real improvement in bean size seems confined to the importation of new varieties from other countries. Small plots from light coloured beans have been planted, the parent trees having been established from introduced seed.

Summary of Selection in Nigeria.

Criteria.

1. Yield in pods per tree. Average over 10 years 70 pods or more. Average over the latter five years 90 pods or more.
2. General appearance. Red pod types discarded.

Precautions taken.

1. Records over one complete season taken in pounds of wet cacao.
2. Conversion of previous pod records into weight of cacao.

Selection in Java.

Selection was started in 1912 on a number of estates (10) but owing to various vicissitudes little attention was subsequently paid to the mother trees or their offspring. Gardens established with seedlings and buddings from these selections yielded little evidence of the comparative merits of the two methods, or of the value of the mother trees for propagation. In 1924 a new start was made. Some trees of the earlier plantings were rediscovered, labelled and propagated by budding, but it was not till 1928 that individual observations were commenced on a number of seedling trees, themselves the F1 of former selections (8).

Records on these, kept in pods per tree, allowed reselection by the "Best quintile and bisquintile" methods now usually adopted in Java. This routine necessitates yield records of all trees in a plot, and using the trees in the plot itself to act as the standard on which to judge individual performance. The quintile is the highest yielding fifth of the field's population; the bisquintile the highest yielding fifth of the quintile. In a plot of 200 trees the quintile would be composed of the 40 best trees and the bisquintile the eight best of those. By this means the influence on yield of soil and locality is largely eliminated, and where soil variation is known to occur, a field is divided for the purpose of determining quintiles. Trees finally selected should fall within the best quintile or bisquintile for two, or preferably more, years. A few trees from the middle quintiles were generally selected to act as controls in later propagation trials.

Frequently high yielding selections were noticed to have thicker trunks, and to be border trees or surrounded by one or more vacancies. It was just to modify the yields from such trees that selection in Trinidad insisted on working out the rate per acre at which these yielded.

Cacao in Java suffers severely from *Helopeltis* and moth attack. While it was found that *Helopeltis* damage was indiscriminate, moths showed preference for the rougher types of pod. Selection has paid particular attention to eliminating such trees, and hopes have been expressed that resistant strains will be established.

As a result of selection in 1928 and 1929 three estates supplied a total of 66 very good yielders with 115 trees in reserve together with 15 medium yielders for comparative purposes. Seventeen trees at one estate—Djati Roenggo—gave an average of 175 pods per year for 1928 and 1929. The highest yielding tree averaged 243 pods for these two years.

A paper (52) recording work done in 1930 and 1931 shows that the criteria of selection were broadened to include considerations of quality, which here implies the absence of purple pigment in the beans. Following the researches of Wellensiek (53) it was established that the presence or absence of purple was controlled by genes and that absence of colour could be regarded as a simple recessive character. Certain previous selections throwing only purple beans were discarded, and others with a proportion of white beans substituted. Crosses were made between Criollos and Forasteros.

In general, although selection has been made exclusively on number of pods, recently modified to discard trees bearing only purple beans, no attempt has been made to allow for tree size, and little attention has been paid to pod value. "We have not at our disposal guiding lines which enable us to judge what connection exists between the number of pods and the output." The examination of beans for colour does, however, necessitate the opening of a number of pods, and notes on shell thickness can be made.

Summary of Selection in Java.

Criteria.

1. Yield in pods per tree. Average over two or more years to fall within the best quintile or bisquintile.
2. Tree to yield a proportion of white beans.
3. General appearance and resistance to moth.

Precautions taken.

1. Yield records taken for more than one year.
2. Elimination of environmental influence by the "best quintile" method of selection.
3. Examination of bean colour.
4. Selection on a number of estates.

Population.

No definite figures available.

Testing of Selections.

Selection is a means—a most important and essential means—towards an end. Unless the selected trees can hand on their desirable qualities to their offspring, they are valueless. Selection therefore, has to be followed by experimental tests to determine which give rise to the best progeny. Such trials are of necessity expensive in management, difficult in layout, and greedy of land, but above all, many years must elapse before results appear. Unless laid down and uniformly cultivated with a view to statistical analysis of accurately determined yields, progeny trials may give little useful information, or even be misleading. These considerations of time and expense make it of the utmost importance to guard against error in the parentage—particularly the male parentage of the progeny—or if clonal material is to be tested, to be sure that bud wood or cuttings are taken from the appropriate selected trees. It may seem surprising that such self evident precautions have not always been adopted in the past, but progeny trials with open pollinated seed of unknown male parentage have been the rule in Trinidad and are believed to be the present practice in Java.

In Trinidad, the Imperial College Selections are now being vegetatively multiplied by cuttings and buddings sufficient for a detailed clonal trial. In due course seedling progenies, either from self- or cross-fertilized seed are to be laid down so that the value of the original selections, either vegetatively or seminally reproduced, can be determined.

The testing of selections in Nigeria (51) has been less difficult since trials of vegetatively produced offspring have been disregarded, and the absence of incompatibility allows the control of the male parent by self-fertilization. Extensive progeny trials at three experimental stations are being established with self-fertilized seedlings. At the same time budded plots of each selection have been grown, so that self-fertilized seed of whichever selection is finally proved will be available in quantity.

In Java the procedure has been to lay down budded plots of each selection together with seedling plots. The variation within budded clones due to the use of seedling root stocks has been noticed, but no successful technique of establishing cuttings has been evolved. Though the original seedling test plots appear to have been planted with self-fertilized seed, the difficulty of obtaining sufficient seems to have led to the use of open pollinated seed in the progeny trials of the more recent selections. Admitting possible invalidity on the score of insufficient material, Wellensiek and de Haan (52) remark on the yield records of seedling and clonal progenies. Seedling plots gave a higher degree of variability between individual trees than the more uniform clones, thus confirming Pound's (24) work on the variability of budded cacao, and in Java the seedlings gave a greater average yield. It is possible that no greater reliance can be placed on the Java yield results of clones *versus* seedlings than can be placed on similar trials laid down several years ago in Trinidad. An essential feature in such trials appears to be an equal degree of pollen compatibility in each selection.

Propagation.

A number of papers in the Cacao Research Reports deals with this subject. Budding has been known and practised—though never on a large scale—since early in the century, and marcotting has on occasions been employed. The technique has been fully worked out and is comprehensively summarized by Pound (25). The chief interest lies in the incompatibility of certain scions for seedling stocks. Doubt exists

whether this is due to genetic or physiological causes. These latter were found to influence profoundly the success or failure of a bud "taking." Thus buds chosen from young trees almost invariably "took" better than buds from old trees. In nursery practice, too, failure, presumably brought about by physiological causes, sometimes results from apparently ideal stock and scion material.

Budding affords an easy and cheap method of clonal multiplication and has been used as such in Trinidad, Nigeria and Java, but the variability caused by seedling rootstocks is a serious drawback where material is required for critical examination.

To eliminate this variability, it was considered essential to work out a method of reproducing clones on their own roots. The successful conclusion of this investigation is one of the most important results attained by the Imperial College of Tropical Agriculture. The technique now employed relies on the use of semi-soft wood cuttings, struck in propagators designed to control temperature, light and humidity. After rooting in the somewhat coarse calcareous sand of the propagators, the cuttings are transplanted into baskets containing rich soil, where some further control of atmospheric conditions can still be maintained (4, 6, 36). Cuttings taken in this manner, whether they be from chupons or fans, develop into trees with root systems almost indistinguishable from trees grown from seed, and in general vigour above ground there appears no difference (7). Though the production of rooted cuttings has scarcely reached the stage of economic application to estates, the method is sufficiently easy and reliable to supply plants for the numerous problems which await such clonal material for their elucidation.

Propagation by seed is the method by which the bulk of the world's cacao is grown. An attempt to eliminate in some degree the variability caused by the use of seedlings has been introduced in Java where the examination of cotyledon colour before planting is advised. Fields planted with seedlings grown only from pale beans will undoubtedly reduce the proportion of dark purple beans. Again, should it ever be required, fields of only coloured or yellow pod cacao could be established if the seedlings were rogued according to presence or absence of axil spot. Perhaps, too, some greater uniformity within seedling trees would occur if the male parentage were controlled.

A point of some advantage in the use of seed is the comparative ease of transference from one locality to another. The duration of viability is, however, not great. Pyke (37) has shown the optimum conditions under which cacao seed in pods can be kept and still maintain the power of satisfactory germination. Provided fungal decay and desiccation are prohibited, pods stored for periods up to seven weeks at temperatures around 60°F. will yield viable beans.

Pollen Incompatibility.

The enormous number of flowers produced by cacao trees and the very low percentage which become cherelles are subjects which have long received attention. During the last six years substantial advances have been made in the discovery of factors influencing the normal loss of some 95 per cent. of flowers. The evidence summarized in the "Economic Botany of Cacao" (3) led to the conclusion that the fertilization of flowers, and later development of the pods, proceeded along normal lines, and that flowers not pollinated would fall within a few days of opening. By the use of glass tubes (26) in Trinidad and match boxes (44) in Nigeria possible agents of pollination have been excluded from a number of flowers, and the shedding of these within three days after anthesis confirms this statement. Pound (27) has suggested that the abscission mechanism causing this fall is due to morphological peculiarities of the pedicel. If inadequate pollination were the reason for the high percentage loss of flowers within the first three days, then hand manipulations to insure ample pollination of the stigmata should result in an appreciable diminution of this loss. Rather naturally the first experiments dealt with self-pollination, *i.e.* using pollen from the anthers on the stigma of the same flower. While this reduced the loss of flowers on six Nigerian trees to only 30 per cent. fallen at six days from pollination (45), in Trinidad a startling tree to tree variation was noted by Pound (28, 29). He found that at six days from pollination some trees lost none of the flowers so treated, but other trees failed to keep a single flower, and he found still other trees which lost varying percentages of flowers.

The low set obtained from self-pollination on some of the Trinidad trees under examination led to the trial of cross-pollination. It was found that the percentage setting was materially increased by the use of "foreign" pollen, especially was this so if the "foreign" pollen were taken from a tree known to give a good set with its own pollen. This, then, confirmed the evidence that pollination need not necessarily result in fertilization, and that there must be some inhibiting factors in the pollen itself or in the female sexual mechanism. The fact that pollen from one tree would not cause fertilization on the flowers of a second tree but would do so on the flowers of a third, coupled with the discovery of adequate pollen germination, pointed strongly to aberrations in the ovules. But flowers unable to set with their own pollen reacted most favourably to pollen from another tree, provided the flowers on that tree could be self-fertilized. This equally pointed to aberrations in the pollen. Similar phenomena occur in other plants and have been termed "Incompatibility." Neither the pollen nor the ovule apparatus is at fault by itself; only when they meet are factors brought into play which may prevent fertilization.

The discovery by Pound of incompatibility in cacao, not to be confused with complete male or female sterility (30), has been one of the outstanding features of recent research on that crop, and the implications are far reaching. The suggestion that self-incompatibility is seasonal in its occurrence (31) has been queried by further experimental data (46). Particular importance should be paid to the observation from Nigeria (43) that certain introduced types, not of the ordinary West African cacao, failed to set fruit on self-pollination, and behaved in all respects as self-incompatible trees in Trinidad. There is, therefore, good evidence for considering incompatibility to be dependent on factors other than seasonal, climatic or nutritional. By a process of elimination, and in line with certain other crops, incompatibility may at present be considered to be governed by genetic factors.

There is as yet little knowledge as to the immediate results of incompatible matings. Initial growth stimulation of the pistil has been noticed, but such growth is arrested early in the development of the fruit, and within a fortnight from pollination abscission has almost invariably occurred (47). The delay in abscission makes it necessary to decide on a reliable time interval from pollination to the date at which a flower is considered set. Thus an incompatible mating may give a high percentage set at five or six days, but nil set at fourteen. It is not known whether the pollen tubes of incompatible pollen reach the ovary, though Posnette (21) has adduced evidence to show that the tubes may fail to grow down the the style. Still less is known whether the male nuclei, if the pollen tubes do reach and penetrate the ovary, connect with the ova but fail to fuse, or whether death of the fertilized ova follows fusion.

Implication of Self-Incompatibility.

Trees which cannot set fruit with their own pollen must rely on foreign pollen if they are to produce any crop, and the pods from such trees must be cross-fertilized. The progeny of self-incompatible trees have been examined, and the results confirm the occurrence of cross-fertilization (48). Pound (28, 29) and later Voelcker (46) were unable to record any satisfactory setting between self-incompatible trees; to yield a reasonable set one or both of the parents had to be a self-compatible tree, but both authors were working with limited material, and it is possible that further data will bring to light instances of good setting between self-incompatible trees. At the moment it is assumed that the self-compatible trees act as pollenizers, and on them alone rests the responsibility of making any yield possible.

The proportion of self-compatible trees within a field of cacao appears, therefore, to be of considerable importance. Out of 27 trees examined Pound (28, 29) recorded 13 self-compatible and Marshall (20) working on another group of 21 trees found 14 self-compatible. Voelcker (46) using a 14 day interval instead of the six or seven day period, classified five trees self-compatible out of 19 trees tested. Further work on a population of several hundred trees showed a high proportion to be self-incompatible (49). The depressing effect on yield which a high proportion of self-incompatible trees may exert has been suggested, and the apparent absence of self-incompatibility in the West African type of cacao may be one cause of the high yields obtained from that coast.

Cross-fertilization, now proved to be of extensive occurrence, also implies some agent of cross-pollination, and this is dealt with in a subsequent paragraph.

The presence of incompatibility factors may account for part of the losses found by Pound (34) to occur in the ovules at fertilization. He noticed that the variation in number of beans from pods of the same tree was much larger than the variation in the number of ovules. Losses of ovules were found to be of two kinds, one relatively constant and the other irregular.

In concluding this summary of the present knowledge of pollen incompatibility it will be realized that only the elementary bare facts of its existence have been investigated. The urgent problems of its effect on yield, and whether its incidence can be reduced or eliminated by plant breeding methods await further research. The continued study of these problems holds a promise of direct practical benefit to those cacao growing countries in which self-incompatibility is found to occur, and should give a clear warning of danger to other countries which may be tempted to introduce unknowingly strains of cacao carrying incompatibility factors.

Flowering, Natural Pollination and Fruit Setting.

A number of papers in the Annual Reports of Cacao Research deals with these subjects. Pyke (38) and Pound (29) have traced the fluctuations which occur in the incidence of flowering and setting in Trinidad. They have shown that there is little, if any, correlation between the two. Thus after the first rains flowering is particularly abundant and setting practically non-existent. Flushes of flowers proceeded intermittently throughout the wet season accompanied periodically by heavy setting. Pyke remarks on the apparent occurrence of two types of trees, the intermittent and continuous setters. To explain the periodic bursts of setting Pound tentatively suggested that physiological causes, mainly nutritional and bound up with the carbohydrate and nitrogen metabolism of the tree, were intimately concerned. To test this assumption he carried out observations on the flowering and setting of ring barked branches. Although this manipulation caused a great increase in flowering and setting, the percentage of setting remained substantially the same. Experiments to determine the effect of artificial manures failed to alter the periods of setting (32, 33). Unfortunately flower counts were not made, and the increased intensity of setting recorded as a result of the

manures may only signify an increased intensity of flowering. The general results of these experiments point to the fact that, whereas the incidence of flowering may be controlled in extent, but not in time, by alterations of nutritional status in the trees, the incidence of setting, recorded as a percentage of flowers produced, remains unaltered both in extent and in time. Voelcker (46) would assume this to be the logical conclusion if setting were solely dependent on some outside factor, in this case the deposition of compatible pollen on the stigma. The periodic bursts of setting would be directly correlated with the incidence of agents of pollination, but he brings forward no evidence of such correlation.

Literature in the past has dwelt on the fact that only about five per cent. of flowers ever receive pollen. However, in view of the periodic heavy setting shown to occur at certain periods by Pyke and Pound, one would expect wide fluctuations in the percentage of flowers receiving pollen. These fluctuations have been demonstrated by Wellensiek (54) in Java. By the microscopical examination of stigmata he found on certain days that up to 47 per cent. of flowers had been pollinated. From general observation in Trinidad and in Nigeria, Voelcker has noted periods of natural setting in which a high proportion of flowers results in cherelles. Owing to the periodic nature of this phenomenon, percentages of flowers pollinated should always be quoted with the dates over which observations were made.

Again in Java (52), the normally small proportion of flowers pollinated led to the trial of artificial hand-pollination. The increase in the number of pods harvested was, however, not significant. It would be interesting to know whether the pollen used was compatible with the trees on which the experiment was made.

Agents of Pollination.

The incidence of heavy yielding self-incompatible trees, and the direct examination of seedling progeny have proved a high degree of cross-pollination in Trinidad. While it is easy to account for some pollination, later resulting in fertilization, on self-compatible trees by the agency of ants and aphids, it is less easy to credit these insects with carrying pollen from one tree to another. Working with self-compatible trees, Posnette (21) found that two trees surrounded by fine cloth set six flowers out of 2,543 during a period of 91 days. Two similar trees with insect proof girdles set 112 flowers out of 8,856, and two completely unguarded trees set 116 flowers from 2,217. The results confirm the fact that pollination must occur before setting, and that both crawling and flying insects are involved. This is in line with previous investigations by Harland and Stahel.

Transference of pollen to the stigmata by wind appears to be the accepted theory in Java. Thus de Haan (11), " Insects play a subordinate part in Java as regards the pollination of cacao. . . . The opinion which is most current is that the pollination is brought about by wind whereby the flowers are set shaking ". So also Wellensiek (54) " Pollination by means of insects therefore does not appear to come into consideration in Java." This author, while admitting the absence of critical tests, also assumes that consequent on wind pollination, self-fertilization rather than cross-fertilization occurs. It is difficult to reconcile this assumption with his remark that where Criollo trees were planted next to Forastero, practically all the Criollos contained a proportion of purple beans indicating cross-pollination. An examination of the flower, and an appreciation of the very scanty supply of pollen, make it difficult to believe that mere shaking would effectively place sufficient pollen grains on the stigma; still less easy is it to imagine the transference by wind of pollen from one tree to another. Added to which is the general observation that setting will take place in the very still atmosphere of sheltered valleys.

Whatever the agents of pollination may be they appear inadequate at certain seasons, while at other periods the considerable setting which sometimes occurs suggests an agent or agents far from inefficient. As in detective fiction, the murder has been proved by incontestable circumstantial evidence but the murderer and his technique await the opening of another chapter.

Cherelle Wilt.

Undoubtedly one of the most obvious causes of loss in yield, cherelle wilt has so far proved a baffling problem and our present knowledge of the fundamental factors governing it is scanty. Pyke (38) has presented data which confirm the impressions of planters and those interested in the cultivation of cacao. He remarks that the tendency of a proportion of young pods to wilt is a constant feature, but that individual trees vary greatly in this respect. While cherelle wilt may account for a loss of 92.5 per cent. of young pods on some trees, others will only lose 19 per cent. The average loss of cherelles from all the trees examined was 69 per cent. Similar figures have been obtained in West Africa by Hewison and Ababio (16). Of particular interest is Pyke's conclusion that there appeared no very close connection between the percentage of wilting and the final crop, due no doubt to the wide fluctuation between trees in the number of cherelles set. The incidence of wilting was found to be associated with a change of leaf and occurred with a well marked intensity when the young fruit were seven to eight weeks old, thus confirming observations by other workers. Pound (32, 33) has shown that the use of fertilizers failed to alter the periods during which susceptibility to wilt was most prevalent.

The observations outlined above had been made on an extensive scale and applied to the incidence of wilt on young fruit set as a result of natural fertilization. As has been already shown,

natural fertilization does not occur uniformly throughout the year, but in a series of greater or lesser jerks. These discontinuous jerks of setting have been eliminated in the data on cherelle wilt presented by Voelcker (45, 47). On six trees in Nigeria and on five trees in Trinidad he fertilized a number of flowers daily over the whole year and recorded the time interval between fertilization and wilting. Thus factors influencing the incidence of wilt could have full play on approximately equal numbers of young fruit of all ages. The Nigerian and Trinidad figures were remarkable for their similarity, and no greater incidence of wilting was noticed at the seven to eight week period than at other age intervals. He concludes from this that the cause of wilt is to be sought in the physiological state of the tree itself, and not, as has been suggested, in the cherelle which at 50 days old is commencing zygotic divisions.

The time of year was found to influence profoundly the incidence of wilt on the cherelles of the Nigerian trees. For the first fortnight after pollination at all seasons losses were very heavy, possibly due to defects in actual hand-pollination, but after that period the season determined the behaviour of the cherelles. In February, March and April shedding was continuous up to the fiftieth day from fertilization after which no further shedding occurred. In the later months of May to September very few losses were recorded between the tenth and thirtieth days, but after that shedding was severe up to the eighty-sixth day from fertilization. In discussing the influence of foliar flushes on wilt, Voelcker remarks that these flushes do not influence the occurrence of losses during the first fortnight, nor do the flushes effect the " twenty-day safety zone " through which cherelles pass between the tenth and thirtieth days in the period May to September.

While further work on cherelle wilt may yield valuable information, it would be unduly optimistic to expect much until clonal material can be used as the basis for observation.

Cultivation.

Cacao cultivation is an art which can only be acquired by long practical experience and, being an art, revolts against hide bound formulae. But though the expression of art is essentially individualistic, certain fundamental laws have to be obeyed. Recent research on cacao has in some degree attempted to define these fundamental laws and to differentiate between these and the individual expression of them. To quote but one example ; in Trinidad cacao trees have been found to benefit by pruning in such a way that the leaf canopy is temporarily opened, and Immortel shade is desirable. In West Africa the cacao canopy is closed and no shade trees are planted. Opening of the canopy may result in rapid deterioration and death. These two systems are individual expressions of one common law concerning the essential environment of cacao. Confusion between fundamental laws and superficial differences has led to misunderstanding, and many questions of practical importance to planters cannot receive a cut and dried answer. Thus optimum planting distance or manure will vary according to soil type, and the results of experiments on one type will only hold good for similar types. With the notable exception of the fundamental work on the nutrient requirements and environmental conditions necessary for the expression of healthy growth and high yield, carried out under Hardy by McDonald (18, 19) at the Imperial College of Tropical Agriculture, research on cultivation over the last few years has been confined to trial and error experiments, and the results of many of these have yet to come to hand.

Soil Requirements.

The soil requirements of cacao have been summarized by Jacks (17) from the work of Hardy in Trinidad, and a summary has also been presented of the soil types found in Brazil, Ecuador, Venezuela and West Africa. The following is a quotation of Hardy's conclusions given by Jacks :

" *Soil Reaction.*—The cacao tree appears to be tolerant of a wide range of soil reaction, the optimum reaction being slightly on the acidic side of neutrality. A highly acidic reaction occurring in heavy clay soils may be taken as a sign of physical conditions unsuitable for the growth of cacao.

" *Texture.*—One of the primary requirements of a good cacao soil is an even moisture status, that is, the soil must not dry out quickly, nor be subject to waterlogging during wet weather. Optimum texture condition will, therefore, vary with climatic and environmental factors. Good natural drainage is essential, but light sandy soils are only suitable for the growth of cacao in well sheltered moist environments.

" *Calcium Carbonate Content.*—The lime content of cacao soils does not appear to exert an important influence on their fertility, since productive cacao occurs on both calcareous and on non-calcareous soils.

" *Organic Matter and Carbon-Nitrogen Ratio.*—High yielding cacao soils generally have a high content of organic matter in their surface layers. The conservation of the surface layer of litter or decomposing vegetation appears to be a very important factor in the maintenance of high yields in the West Indian cacao fields. The C/N ratio of the organic matter is generally much higher in good yielding than in poor yielding fields.

" *Harmful Factors.*—In a number of clay soil types occurring in Trinidad poor growth and yield of cacao are often associated with a high content of gypsum in the sub-soil layers, and have led to the conclusion that excessive quantities of calcium sulphate in the soil may adversely affect the growth and yield of cacao.

"*Total Nitrogen.*—West Indian soils appear to be generally well supplied with nitrogen, no definite differences having been found between the nitrogen contents of high and of low yielding oils.

"*Available Phosphate.*—One of the most striking features of West Indian cacao soils is a marked deficiency of available phosphate in the poorer types of soil. High yielding soils generally have a high available phosphate content.

"*Available Potash.*—Adequate supplies of available soil potash are essential for the optimum growth and yield of the cacao tree."

Quoting from the same summary, Greenwood's determinations of first foot soil samples collected from thirty-six soils throughout the Gold Coast Cacao belt are of interest.

	Sand %	Clay %	pH	N %	C : N	Available P_2O_5 p.p.m.
Mean	66	15.6	6.0	0.098	11.4	18.2
Range	(41-82)	(10.8-32.4)	(5.5-6.7)	(.005-.213)	(8.9-13.0)	(7.3-8.0

The effect of soil type on longevity and yield has been clearly demonstrated by Shephard (42) in a series of papers dealing with the economic aspects of cacao cultivation in Trinidad. He suggests that the cultivation of cacao should be confined to soil types known to be suitable for the growth of the crop, and that soil types on which cacao does not thrive should be abandoned to other agricultural uses.

Atmospheric Environment.

Hardy and McDonald (18, 19) have attempted to define the essential conditions of humidity, temperature, solar radiation and rate of evaporation associated with healthy growth and efficient yield. By comparing the conditions found to exist in a good plot with those in a bad plot, these authors have shown that the bad plot is characterized by extreme fluctuations. Fluctuations naturally occur to some extent on the good plot according to the season, but they are greatly accentuated on the bad plot. Hence shade, windbreaks and drainage all tend to stabilize the atmospheric conditions, and by doing so reduce the tendency of frequent leaf fall and growth flushes which in turn, were found to be detrimental to flowering and the development of cherelles.

Manurial Experiments.

Consequent upon the extensive analytical data of Trinidad soils carried out under Hardy, numerous manurial experiments have been initiated. It is impossible here to record the details of these experiments which from time to time have been dealt with in these Annual Reports. Outstandingly beneficial results have been obtained from the use of phosphatic manures on certain soil types previously shown to be deficient in available phosphate. Generally, nitrogen additions have had little effect on yield. Potash deficiency has been found associated with the incidence of marginal leaf scorch (15). As has been mentioned before in this summary, it is not yet known at what stage in crop production a manure found to increase yield acts. Thus, the increase in pods harvested following the use of phosphate on the calcareous marls may be the result of more extensive flowering, or of a higher percentage setting, or of less cherelle wilt.

The discovery of mycorrhiza (39) in the roots of cacao may influence profoundly the uptake of nutrients, and its significance has been discussed by Pyke.

In Ceylon (40), a manurial experiment to test the influence of superphosphate and potash on yield and on pod canker gave no results in favour of the manures. Similarly, experiments in the Gold Coast (41), though showing slight increases in yield from the manured plots, failed to demonstrate the economic use of such fertilizers.

Rejuvenation.

Even on the best cacao soils, Shephard (42) has shown that a number of stands gives little or no yield. Such stands either are blanks due to the death of the trees, or are populated with poorly grown or damaged trees, or trees genetically incapable of bearing a crop. He suggests that vacancies should be supplied with the best cacao planting material, and that trees, which for any cause consistently give very poor yields, should be replaced by supplies. Work of this nature is suggested in Java (52) and Nigeria. Shephard recommends modifications in the traditional methods of supplying to overcome the practical difficulties hitherto experienced in bringing into early bearing young supplies planted through old cacao. He condemns as unprofitable any attempt to 'supply' defective soils. The alternative method of cutting out all the cacao from old low yielding fields, and replanting throughout, is also being tested.

Diseases.

No summary of recent literature on cacao would be complete without a reference to the invasion of Witchbroom into the Trinidad estates and the methods adopted for the control of that disease. While the disease has spread slowly in the northern part of the island, low lying areas on the east have been heavily infected. In one such area the Department of Agriculture, Trinidad, has done considerable experimental work and has successfully controlled the disease by the frequent cutting off of brooms. Briton-Jones and Cheesman (1) have suggested methods of cutting off brooms, and of general pruning, to limit the number of growing points at which infection can take place. Reports of this control work are to be found in the Administration Reports of the Director of Agriculture. Periodic cutting and removal of brooms is now practised by a number of estates.

Expeditions to Ecuador and the Amazon valley have been made in a search for resistant strains. Seed from trees apparently resistant is now being tested (35).

On the West Coast of Africa, black pod disease (*Phytophthora* spp.) has received attention by Dade (9) in the Gold Coast, and by West (55) in Nigeria. Both authors recommend, as the most practical method of control, regular and frequent harvesting, and the early removal of infected pods.

In the Gold Coast (12) the incidence of a new disease, termed swollen shoot, has been noticed. The disease appears to be associated with a faulty environment (13).

Acknowledgment.

The writer is particularly indebted to the Deputy Director, The Imperial Bureau of Plant Genetics, Cambridge, for full translations of recent Dutch publications. From the more important of these full translations a summary of the cacao work in Java has been made possible.

Bibliography.

1. Briton-Jones, H. R. and Cheesman, E. E.—A New Aspect of Witchbroom Control in Trinidad. *Tropical Agriculture*, VIII, 79-89, 1931.
2. Cheesman, E. E.—*Empire Jnl. Exptl. Agric.*, 1938. (In the Press.)
3. Cheesman, E. E.—The Economic Botany of Cacao. A Critical Survey of the Literature to the end of 1930. Supplement to *Tropical Agriculture*, June, 1932.
4. Cheesman, E. E.—The Vegetative Propagation of Cacao. *First Annual Report on Cacao Research* (1931), 1932.
5. Cheesman, E. E. and Pound, F. J.—Further Notes on Criteria of Selection in Cacao. *Third Annual Report on Cacao Research* (1933), 1934.
6. Cheesman, E. E. and Spencer, G. E. L.—The Vegetative Propagation of Cacao. VI. General Notes on Technique with Cuttings. *Fifth Annual Report on Cacao Research* (1935), 1936.
7. Cheesman, E. E.—The Vegetative Propagation of Cacao. VII. Root Systems of Cuttings. *Fifth Annual Report on Cacao Research* (1935), 1936.
8. Cohen Stuart, C. P. and Haan, J. T. De.—Verslag over de Cacao Selektie in de Jaren 1928 en 1929. *Arch. Koffiecult. Ned.-Ind.* 4 : 111-175 : 1931.
9. Dade, H. A.—Recent Research on Empire Products.—*Agricultural Bulletin of the Imperial Institute*, XXIX, 1932.
10. Haan, J. T. De.—Review of the Cacao Selection Experiments in Mid Java. *Fourth Pacific Science Conference*, IV, 1929.
11. Haan, J. T. De.—Korte Gegevens Betreffende de Cacao-cultuur. *Arch. Koffiecult. Ned.-Ind.* VII, pp. 74, 1933.
12. —— —A New Disease of Cacao in the Gold Coast. *The Gold Coast Farmer*, V, 7, 1936.
13. —— —Editorial. *The Gold Coast Farmer*, VI, 5, 1937.
14. Hardy, F., McDonald, J. A. and Rodriguez, G.—Cacao Soil Survey. *Fourth Annual Report on Cacao Research* (1934), 1935.
15. Hardy, F.—Cacao Soil Investigations. II. Marginal Leaf Scorch of Cacao. *Sixth Annual Report on Cacao Research* (1936), 1937.
16. Hewison, H. K. and Ababio, N. K.—Flower and Fruit Production of Theobroma Cacao. Gold Coast Dept. Agr. *Year Book*, 1929 (*Bull.* 22), (87-94) 1930.
17. Jacks, G. V.—Tropical Soils in Relation to Tropical Crops. 10. Cacao. Imperial Bureau of Soil Science. *Technical Communication*, No. 34, 1936.
18. McDonald, J. A.—An Environmental Study of the Cacao Tree. *First Annual Report on Cacao Research* (1931), 1932.
19. McDonald, J. A.—An Environmental Study of the Cacao Tree. *Second Annual Report on Cacao Research* (1932), 1933.
20. Marshall, J.—Fertility in Cacao. MSS. Dissertation in Library of Imperial College of Tropical Agriculture, 1933.
21. Posnette, A. F.—Incompatibility and Pollination in Cacao. MSS. Dissertation in Library of Imperial College of Tropical Agriculture, 1937.
22. Pound, F. J.—Criteria and Methods of Selection in cacao. *Second Annual Report on Cacao Research* (1932), 1933.
23. Pound, F. J.—The Genetic Constitution of the Cacao Crop. *First* (1931) and *Second* (1932) *Annual Reports on Cacao Research*, 1932, 1933.
24. Pound, F. J.—The Variability of Budded Cacao. *Third Annual Report on Cacao Research* (1933), 1934.
25. Pound, F. J.—Notes on the Budding of Cacao. *Fourth Annual Report on Cacao Research* (1934), 1935.
26. Pound, F. J.—Note on a Method of Controlled Pollination of Cacao. *Fourth Annual Report on Cacao Research* (1934), 1935.
27. Pound, F J.—Studies of Fruitfulness in Cacao. I. A Note on the Abscission of the Flower. *First Annual Report on Cacao Research* (1931), 1932.
28. Pound, F. J.—Studies of Fruitfulness in Cacao. II. Evidence for Partial Sterility. *First Annual Report on Cacao Research* (1931), 1932.
29. Pound, F. J.—Studies of Fruitfulness in Cacao. III. Factors Affecting Setting. *Second Annual Report on Cacao Research* (1932), 1933.
30. Pound, F. J.—Certain Barren Types of Cacao. *Fourth Annual Report on Cacao Research* (1934), 1935.
31. Pound, F. J.—Studies of Fruitfulness in Cacao. V. Conditional Self-compatibility and its Implications. *Fourth Annual Report on Cacao Research* (1934), 1935.
32. Pound, F. J.—Studies of Fruitfulness in Cacao. VI and VIII. Observations in an Experiment Designed to Test the gross effects of Applications of Nitrogen, Potassium and Phosphorus on the Cacao Tree. *Fourth* (1934) and *Fifth* (1935) *Annual Reports on Cacao Research*, 1935 and 1936.
33. Pound, F. J.—Studies of Fruitfulness in Cacao. X. Physiological effects of Applications of Nitrogen, Potassium and Phosphorus on the Cacao Tree. *Fifth Annual Report on Cacao Research* (1935), 1936.
34. Pound, F. J.—Studies of Fruitfulness in Cacao. VII. Ovule loss at Fertilization. *Fourth Annual Report on Cacao Research* (1934), 1935.

35. Pound, F. J.—Ecuador, its Agriculture in 1937. *Proceedings of the Agricultural Society of Trinidad and Tobago*, XXXVII. Part 9, 1937.
36. Pyke, E. E.—The Vegetative Propagation of Cacao. II. The Rooting of Softwood Cuttings. *Second Annual Report on Cacao Research* (1932), 1933.
37. Pyke, E. E.—On the Germination of Cacao Beans with special reference to Storage and Transport Problems. *Fourth Annual Report on Cacao Research* (1934), 1935.
38. Pyke, E. E.—The Physiology of Cacao. I. General Observations on Growth, Flowering and Fruiting. *Second Annual Report on Cacao Research* (1932), 1933.
39. Pyke, E. E.—Mycorrhiza in Cacao. *Fourth Annual Report on Cacao Research* (1934), 1935.
40. —— —Recent Research on Empire Products. Agriculture. Report of the Experiment Station, Peradeniya. *Bulletins of the Imperial Institute*, XXIX and XXXIV, 1931 and 1936.
41. —— —Recent Research on Empire Products. Agriculture. The Gold Coast. *Bulletin of the Imperial Institute*, XXXII, 137, 1934.
42. Shephard, C. Y.—The Cacao Industry of Trinidad. Some Economic Aspects. Series III. An Examination of the Effects of Soil Type and Age on yield. Series IV. Recommendations for Improving the Efficiency of Estates. 1937.
43. Voelcker, O. J.—Initial Cacao Selection in Nigeria. *Eleventh Bulletin of the Agricultural Department*, Nigeria, 1936.
44. Voelcker, O. J.—On a Method of Controlled Pollination of Cacao. *Tenth Bulletin of the Agricultural Department*, Nigeria, 1931.
45. Voelcker, O. J.—A Study of Controlled Pollination in Cacao. *Eleventh Bulletin of the Agricultural Department*, Nigeria, 1936.
46. Voelcker, O. J.—Self-incompatibility in Cacao. *Sixth* (1936) *and Seventh* (1937) *Annual Reports on Cacao Research*, 1937 and 1938.
47. Voelcker, O. J.—A Note on the Behaviour of Cacao Flowers after Pollination and on the Incidence of Cherelle Wilt. *Seventh Annual Report on Cacao Research* (1937), 1938.
48. Voelcker, O. J.—The Incidence of Cross-pollination in Cacao. *Seventh Annual Report on Cacao Research* (1937), 1938.
49. Voelcker, O. J. and Cope, F. W.—Factors Controlling the Yield of Young Cacao. I. *Seventh Annual Report on Cacao Research* (1937), 1938.
50. Voelcker, O. J.—Recent Researches on Empire Products. Agriculture. Cacao. *Bulletin of the Imperial Institute*, XXX, 1932.
51. Voelcker, O. J.—Recent Researches on Empire Products. Agriculture. Cacao. *Bulletin of the Imperial Institute*, XXXIV, 1936.
52. Wellensiek, S. J. and Haan, J. T. De.—Onderzoekingen over Cacao-selectie in 1930 and 1931. *Arch. Koffiecult. Ned.-Ind.* 6 : 103-45 : 1932.
53. Wellensiek, S. J.—De Erfelijkheid van Zaadlobkleur bij Cacao als basis voor Qualiteitsselectie. *Arch. Koffiecult. Ned.-Ind.* 5 : 217-33 : 1931.
54. Wellensiek, S. J.—Bloembiologishe Waaruemingen aan Cacao. *Arch. Koffiecult. Ned.-Ind.* 6 : 87-101 : 1932.
55. West, J.—Black Pod of Cacao. Experimental Control on Native Farms. *Eleventh Bulletin of the Department of Agriculture*, Nigeria, 1936.

(B) CHEMICAL AND ECOLOGICAL SECTION.

THE CHEMICAL PROGRAMME OF 1937.

By F. Hardy.

Cacao Biochemistry.

The work of the Chemical and Ecological Section for the year 1937 has been seriously interrupted by further changes in staff. The resignation at the end of 1936 of the first Chemical Officer for Cacao Research (Mr. J. A. McDonald) was recorded in the last (Sixth) Annual Report (p. 6). The biochemical investigations of cacao bean begun by this officer late in 1935, were handed over in October, 1936, to the Lecturer in Chemistry (Dr. D. W. Duthie). No chemist for Cacao Research was appointed during the academic year, October 1936-June 1937, and Dr. Duthie continued the investigations, along with his teaching and other duties, with the aid of a temporary junior assistant. In July, 1937, Dr. Duthie was appointed to the post of chemist in the Department of Agriculture of British Guiana and consequently both the posts of Lecturer and of Cacao Research Chemist were vacant during the greater part of the Long Vacation of 1937. In October, 1937, Dr. E. C. Humphries, who had been appointed in London as Lecturer in Chemistry, took up the duties of both posts, with the aid of a junior assistant. Naturally there has been little time for Dr. Humphries to have progressed very far with the biochemical investigations, so that the only completed work for the year 1937 is that accomplished by Dr. Duthie, an account of which appears in this (Seventh) Annual Report.

Gold Coast Cacao Soils.

Soil investigations during the year have mainly concerned the laboratory examination of a second series of Gold Coast cacao soil profile samples collected and forwarded by Mr. M. Greenwood, Chemist of the Department of Agriculture of the Gold Coast Colony. A second article on Gold Coast cacao soils, which appears in the present Report, describes the results of this work.

Trinidad Soil Survey.

During the year under review, Dr. E. M. Chenery, Soil Surveyor on the staff of the Department of Agriculture of Trinidad and Tobago, who was appointed in May, 1936, has continued the mapping of the soils of Trinidad which was begun systematically by Mr. J. A. McDonald in 1931, and continued intermittently by Messrs. McDonald, F. Hardy and D. W. Duthie up to the end of 1935. In June and July, 1936, Dr. Chenery helped in a special-purposes soil survey of the Rio Claro District of South Trinidad; later he commenced a detailed soil survey of the Sangre Grande-Manzanilla District of East Trinidad. During the year 1937, Dr. Chenery has been able to prepare a series of provisional large-scale soil maps covering the greater part of that area. This survey will be completed during 1938, and continue southwards so as to join up the mapping, through the Biche District, with the Rio Claro District. Dr. Chenery has worked in close co-operation with the College Department of Chemistry and Soil Science, and the laboratory examination of a large number of soil samples collected by him has been undertaken in the College laboratories. Thus, during 1937, some 250 soil samples were examined by the Analytical Department by customary routine methods, in connection with the Trinidad soil survey, and this work occupied about 15 per cent. of the total available time in the laboratory.

Manurial Experiments.

The cacao manurial experiments begun in 1932 by Mr. J. A. McDonald, were handed over in January, 1936, to officers of the Department of Agriculture of Trinidad and Tobago; they have since been continued and greatly augmented under the charge of Dr. F. J. Pound, Agronomist, so as to include most of the soil-types in which cacao is grown in the Colony. A summary of Dr. Pound's first year's experiments was given in the last (Sixth) Annual Report, and a summary of the second year's experiments is given in the present (Seventh) Report. Altogether there were forty-four (44) Latin Square (Type A) manurial experiments in being in September, 1937, and the number has been increased subsequently. In addition, a large number (some 160) of acre-block (Type B) experiments were laid down during 1936 and the first half of 1937, as well as a great many planters' experiments of various kinds. In connection with Dr. Pound's cacao manurial experiments, a collection of some 170 surface composite soil samples (Series NPK), procured by Dr. Pound and his assistants, has been analysed in the College laboratories for the purpose of identifying nutrient deficiencies, and as a guide to manurial treatments and liming. This work entailed the expenditure of about 10 per cent. of the total time available in the laboratory.

Ecological Investigations.

Under the circumstances, and mainly owing to shortage of staff and laboratory facilities, a continuation of ecological investigations of the cacao crop in Trinidad has unfortunately been found not to be feasible. Much requires to be done in this direction, particularly in connection with the causes underlying fruit shedding. It is generally agreed that the premature shedding of cacao pods is one of the main causes limiting the size of the crop. A careful assessment of all the numerous factors that contribute to the

processes of abscission, shedding, shrivelling and blackening of young cacao pods, in relation to the fluctuating ecological conditions of the environment and the internal changes within the tree, might reveal the particular responsible factor. The start on this problem, which was made by Mr. McDonald and also by Dr. Pound and Mr. Pyke (Botanical Officers for Cacao Research), needs to be followed up, for it is not yet known whether the chief cause is genetical or physiological, and if the latter, whether or not it is some internal condition of the tree that is primarily influenced by external growth factors dependent on season or climate.

PART I.—CACAO SOIL INVESTIGATIONS.

(1) SOME GOLD COAST CACAO SOILS—SERIES II.

By F. Hardy and E. H. Amoroso-Centeno (*Analyst*).

(I) Introductory.

As a continuation of comparative laboratory studies of typical Gold Coast cacao soil profiles, described in the last (Sixth) Annual Report, a second series of soil samples, 210 in number, representing 21 profiles, has been collected and forwarded by Mr. M. Greenwood, and examined in the College laboratories by our customary routine methods. The complete data were sent to Mr. Greenwood in December, 1937, and are not reproduced here, but the results for the surface six-inch layer are presented in a following table. As for the first series, an attempt has been made to assess the nutrient status of the soil at each profile site by applying an arbitrary scale of marking to the laboratory data, as well as to those for some typical West Indian cacao soils for purposes of comparison. As far as possible, yield data, kindly supplied by Mr. Greenwood, have been included in the table in order to reveal possible relationships between actual productivity and laboratory assessment.

(II) Origin and Relationships of the Soil-Types.

The cacao soil-types of the Gold Coast have provisionally been classified into (A) *Red Earths*, and (B) *Yellow Earths*, in accordance with the characteristic coloration of the profile as a whole. This division is not entirely satisfactory, because many of the profiles show variable mottling in red, orange and ochre-yellow colours within the subsoil (B-horizon), though some are coloured uniformly bright red and some mainly ochre-yellow. Where possible, the Red and Yellow Earths have been subdivided into (I) *Sedentary Soils*, which directly overlie the parent rocks that have given rise to them, and (II) *Alluvial (and Colluvial) Soils*, derived from weathered rock material transported and deposited elsewhere, either by rivers or by gravity. Certain alluvial soils show grey colours in profile, presumably caused by lack of oxidation in the more-or-less waterlogged subsoil.

In certain instances (for example soils derived from Cape Coast Granite and Dixcove Granite), a regular sequence of red gravelly loam to yellow sandy-loam to grey sandy-loam occurs down the slopes within undulating country, the red soils occupying the hill-crests, the yellow soils the sides, and the grey soils the hollows, which are usually swampy. This alternating sequence resembles the " catena " as defined and described by Milne,* and employed by him in the preparation of the East African Soil Map ; it may partly be explained in terms of degree of oxidation and hydration of iron oxide residues derived by the weathering of ferro-magnesian minerals occurring in the parent rocks. Thus, red soils generally owe their colour to the presence of goethite or haematite containing little or no water of hydration, and yellow soils to limonite, which is relatively highly hydrated. On the other hand, cases have been revealed where a red colour is associated with a higher content of ferric oxide in the soil ; for example, the clay fraction of a red soil at Asuansi, Central Province, when chemically analysed, gave an average content of ferric oxide of 9.1 per cent. down to a depth of 4 feet, while a yellow soil from the same district gave a ferric oxide content of 5.1 per cent.†

A close relationship between soil-type and the petrographical nature of the parent rock appears to hold within the Gold Coast cacao belt, so that climatological influences seem to be subordinate to geological. Within the cacao belt, the climate is fairly uniform, coinciding with that of the rain forest belt. The mean annual rainfall ranges from 45 to 75 inches, average, 61 inches, and shows maxima in June and October (of 10 and 8 ins.). There are four dry months, namely December, January, February and August, during which the total rainfall is only 8 ins. Drying winds prevail during December to February (the Harmattan), causing a rapid fall in average humidity (from 80 to 20 per cent.) and seriously affecting the " water balance " between the cacao trees and their environment.

* *Soil Research*, IV, 3, 1935, pp. 183-198.

† M. Greenwood ; private communication.

(III) Petrography of the Gold Coast Rocks and Soils.

The parent rock-types from which the Gold Coast cacao soils have been derived were briefly described in the last report. The Gold Coast geological succession, according to the legends on the maps prepared under the direction of Sir A. E. Kitson (1928) and of Dr. N. R. Junner (1935), is the following :—

	Geol. Age.
(A) Sedimentary Series.	
1. Superficial Deposits ; River and marine deposits.	*Recent.*
2. Apollonian ; Shales, sandstones, limestones.	*Cretaceous.*
3. Sekondian ; Sandstones, grits, shales.	*Carboniferous.*
4. Accraian ; Sandstones, grits shales.	*Mid-Devonian.*
5. Voltaian ; Sandstones, grits, shales, limestones.	*Pre-Mid-Devonian.*
(B) Metamorphic Series.	
6. Akwapimian and Buem ; Quartzites, schists, tuffs.	*Devonian*
7. Tarkwaian ; Quartzites, slates, phyllites.	*Pre-Cambrian.*
8. Upper Birrimian ; " Greenstone" (metamorphosed igneous rock).	do.
9. Lower Birrimian ; Schists, slates, phyllites, ashes.	do.
10. Archaean ; Gneisses, garnetiferous schists.	do.
(C) Intrusive Igneous Series.	
11. Basic Intrusives ; Gabbro, dolerite, &c.	*Post-Birrimian.*
12. Acidic Instrusives	
(i) Dixcove Granite ; Hornblende-granite, diorite, &c.	do.
(ii) Cape Coast Granite ; Muscovite-granite, aplite, &c.	do.
(iii) Undifferentiated Granite.	do.

The Gold Coast cacao soils have been derived mainly from (1) Cape Coast Granite (2) the metamorphosed sediments which comprise the Lower and Upper Birrimian, the Tarkwaian, and the Akwapimian-Buem Series, and (3) the unaltered Voltaian sediments. In Togoland, the cacao soils have been derived mainly from Akwapimian-Buem and Voltaian rocks, and from Archaean gneiss (or Crystalline Series), which occupy the northern part of the cacao region bordering the savannah belt with lower rainfall. The parent rock in all cases is deeply weathered, and is seldom seen in the six-foot profiles. In many instances weathering of the parent rock extends down to the 20-foot depth. The mineral material of the various horizons of the profiles thus consists almost entirely of weathering products, mainly iron oxide-stained kaolin and quartz gravel and sand, with iron oxide concretions of various sizes, and occasional pieces of laterite. The granite profiles usually contain abundant flakes of white mica in addition.

The soils are mainly sandy ; the proportionate amount of clay is variable but generally small, and consists of a low-shrinking kaolinitic type having low base exchange capacity. The content of organic matter in the surface layers is very variable ; its depth of penetration ranges from a fraction of an inch to four or five feet, depending chiefly on the extent of surface erosion or degree of truncation of the profiles, which is generally greatest on hill crests and ridges, and least on slopes and in valleys and hollows containing transported soil.

A regular feature of the Gold Coast cacao soils is the rapid increase in acidity down the profile. The surface layers are frequently alkaline or neutral in reaction, particularly where organic matter is abundant and its carbon-nitrogen ratio is relatively wide. The high pH value of the surface humic layer may be attributed to the mineralisation of the plant residues, consisting of fallen leaves and rotting roots, having high base acid ratio. The bases (potash, soda, lime, magnesia) have been abstracted from the decomposing rock-mass by previous generations of forest trees, and subsequently deposited at the surface by leaf-fall, so that a gradual accumulation of mineral-rich alkaline humus has occurred. Downward leaching of the soluble nitrogenous organic decomposition products of the surface litter has caused infiltration into the subsoil, so that incorporated organic matter having narrow carbon-nitrogen ratio may be traced to considerable depth in the porous sandy substratum.

Effects of Erosion.

The rapid downward diminution in the amount of organic matter with its accompanying mineral nutrients is clearly indicated by the laboratory data for the soil profile layers, especially as depicted on the coloured profile cards. During sampling, the profile was marked out into horizontal layers, whose individual thickness was small near the surface, but increased below. The actual sampling-depths employed in this collection of Gold Coast soils were : 1½, 3, 6, 12, 18, 24, 36, 48, 60, and 72 inches, so that each six-foot profile yielded ten (10) separate soil samples, of which the first three were included in the top 6-inch layer, and the second three in the subsoil layer down to the 2-foot depth, below which, foot layers only were sampled. This procedure has revealed the striking fact that in normal cases the organic matter content of the first 1½ inch-layer is about twice that of the second 1½ inch-layer; that of the first 3 inches, about twice that of the second 3 inches, and that of the first 6 inches about 2½ times that of the second 6 inches. Thus a soil which contains, say, 3 per cent. of organic matter in its upper 6-in layer, will contain about 5⅓ per cent. in its first 1½-in. layer, 2⅔ per cent. in its second 1½-in. layer, and 2 per cent. in its second 3-in. layer. Similar proportionate diminutions are shown by the values for " rate of solution ", indicating that the relative nutrient status of the upper shallow layers of the

profile decreases almost in inverse geometrical ratio from the surface downwards. It is evident therefore that soil erosion, even to a relatively shallow depth of 1½ inches, will greatly diminish the inherent fertility of the soil.

Among the 40 profiles examined, at least 17 show some degree of erosion, and 9 of these are markedly truncated*, their surface 6-in. layer containing only about 1.6 per cent. organic matter of low carbon-nitrogen ratio (9.7), and having a high degree of acidity (pH 5.1) and low rate of solution (30 units). Humic penetration in these soils is less than 2 feet, and they all yield under 700 lb. of dry cacao per acre, the average for the nine eroded sites being only 384 lb. acre.

(IV) Classification of the Soil Profiles.

The following tentative scheme includes all the forty Gold Coast cacao soil profiles so far examined.

(A) Red Earth.

(I) Sedentary.

(1) Derived from *Voltaian* sedimentary rocks
1st Series: Profiles Nos. 13 (Bukrum); 14 (Sesiamang); 15 (Samang); 18 (Kwabea).
2nd Series: Profiles Nos. 23 (Agogo); 40 (Asuefu).

(2) Derived from *Akwapimian-Buem* metamorphic rocks.
1st Series: Profile No. 1 (Aburi).
2nd Series: Profile No. 25 (Adiado).

(3) Derived from *Tarkwaian* metamorphic rocks.
1st Series: None.
2nd Series: Profile No. 30 (Juaso).

(4) Derived from *Upper Birrimian* metamorphic rocks (Greenstone).
1st Series: None.
2nd Series: Profiles Nos. 31 (Konongo): 37 (Bompata 1); 38 (Bompata 2).

(5) Derived from *Lower Birrimian* metamorphic rocks.
1st Series: Profile No. 5 (Kumasi).
2nd Series: Profiles Nos. 32 (Bibiani); 35 (Sefwi-Bekwai).

(II) Alluvial and Colluvial.

(1) Derived from *Akwapimian-Buem* metamorphic rocks.
1st Series: Profile No. 17 (Cherechum).
2nd Series: None.

(B) Yellow Earth.

(I) Sedentary.

(1) Derived from *Cape Coast Granite* acid intrusive igneous rock.
1st Series: Profiles Nos. 3 (Efiduasi 1); 7 (Asuansi 1); 8 (Asuansi 2).
2nd Series: Profiles Nos. 21 (Adawusina 1); 22 (Adawusina 2); 36 (Adeiso); 39 (Ntonso).

(2) Derived from *Tarkwaian* metamorphic rocks.
1st Series: None.
2nd Series: Profile No. 29 (Juansah).

(3) Derived from *Upper Birrimian* metamorphic rocks (Greenstone).
1st Series: Profiles Nos. 11 (Nkawkaw 1); 12 (Nkawkaw 2).

(4) Derived from *Lower Birrimian* metamorphic rocks.
1st Series: Profiles Nos. 6 (Mbeim); 10 (Manhyia).
2nd Series: Profile No. 24 (Atasomanso).

(5) Derived from *Archaean* crystalline metamorphic rocks.
1st Series: None.
2nd Series: Profile No. 28 (Kpedze).

(II) Alluvial and Colluvial.

(1) Derived from *Cape Coast Granite* acid intrusive igneous rock.
1st Series: Profiles Nos. 2 (Efiduasi 1); 19 (Amoyu).
2nd Series: Profile No. 20 (Ampabami).

(2) Derived from *Akwapimian-Buem* metamorphic rocks.
1st Series: Profile No. 16 (Okrakwajo).
2nd Series: Profiles Nos. 26 (Amimle); 27 (Akome Agate).

(3) Derived from *Upper Birrimian* metamorphic rocks (Greenstone).
1st Series: None.
2nd Series: Profile No. 33 (Wiawso).

(4) Derived from *Lower Birrimian* metamorphic rocks with intruded Undifferentiated Granite and Dixcove Granite.
1st Series: Profiles Nos. 4 (Dotum); 9 (Nkawe).
2nd Series: Profile No. 34 (Brofuyedru).

Detailed descriptions and full laboratory data for each of these forty profiles are filed in the offices of the Chemistry Division of the Gold Coast Department of Agriculture at Accra, together with hand-painted profile cards which pictorially present the data for reaction, texture, organic matter content, rate of solution (electrical conductivity) and available phosphate (Truog method), for the different layers of each profile. Generalised descriptions of (1) Voltaian Red Earth, (2) Metamorphic Red Earth, (3) Alluvial Red Earth, (4) Granite Yellow Earth, (5) Metamorphic Yellow Earth and (6) Alluvial Yellow Earth were given in the report on the First Series of profiles; the Second Series examples do not deviate greatly from them, so that no further descriptions need here be attempted.

The following additional notes, however, may serve to convey a clearer impression of the main features and degree of variation of the soil-types.

(1) The *Voltaian Red Earth*, occurring within the Krobo District, is represented among the Second Series by two much less nutrient-rich soils (Nos. 23 and 40) than the four examples of the First Series. The productivity of this soil-type is very variable, and seems to be determined largely by the organic matter content and its depth of penetration, which may depend on the length of time that erosion or wastage has operated. Parts of the Krobo

* Profile Nos. 4, 8, 10, 20, 22, 23, 24, 30, 34.

cacao area have recently been taken in from forest; the nearness of the savannah belt lying to the north, the tendency to low rainfall, and the sparseness of shelter or shade, may account in some cases for low productivity. The parent material of the Voltaian soil appears to be mainly sandstone and not limestone as postulated in the last report.

(2) The *Akwapimian-Buem Red Earth*, represented by two sedentary profiles and four alluvials, is believed to be the most fertile cacao soil in the Gold Coast,* and much favoured by farmers. It is a red loam of great depth, with variable amounts of quartz gravel in the surface layers and at different lower levels, overlying red and yellow-mottled rotten quartzite or schist rock.

(3) The *Tarkwaian Red or Yellow Earths*, not represented in the First Series, are exemplified by two (probably truncated) profiles (Nos. 29 and 30) situated near the north-central border of the cacao belt (Ashanti-Akim Province). They resemble the soils derived from similar metamorphic rocks comprising the Birrimian Series.

(4) The *Birrimian Red or Yellow Earths* are represented by 15 profiles, four of which are alluvials. The colour is variable, and mottling in red and yellow tints renders their classification difficult. Usually, bright red profiles predominate. A distinguishing feature seems to be the paucity of gravel, but this is by no means an invariable attribute, owing to the fact that a wide range of rock-types forms the parent material. The fertility of the Birrimian metamorphic soils is variable, though generally medium to poor.

(5) The *Archaean Yellow Earth* is represented by one profile only (No. 28; Kpedze). This is derived from a crystalline gneiss, which appears, partly rotted, below the 2½-foot depth.

(6) *Intrusive Igneous Soils* mainly comprise Yellow Earth derived from Cape Coast Granite (10 profiles). The soil is a grey-brown sandy-loam containing fragmentary quartz and ironstone concretions between the first and second foot depths, set in reddish clay, and underlain by smooth, coarsely-mottled, ochre-brown and creamy white, friable, kaolinitic clay, containing abundant flakes of white mica. On the ridges, the profile is truncated, so that the gravel layer lies near the surface, and the soil consequently tends to dry out rapidly. An example of a truncated Granite Yellow Earth profile is No. 22 (Adawusina 2), whose surface layer actually corresponds to the subsoil of another Adawusina profile (No. 21).

(V) Fertility Status of the Gold Coast Cacao Soils.

General Discussion.

A provisional scheme for assessing the fertility status of West Indian cacao soils has been evolved at the College as a result of accumulated experience. This scheme involves the assignment of marks to the numerical values for different soil constants obtained by laboratory examination of the surface six-inch layers of soil profiles. Limits of adequacy have been tentatively derived from the results, so that the main nutrient deficiencies of the soil may readily be identified. The information thus obtained has been used mainly in designing manurial experiments for the large number of cacao soil-types that occur in the West Indies region. The procedure is subject to all the criticisms usually attending "rapid chemical methods" of soil analysis, and its application is warranted only when a sufficiently large mass of laboratory data has been accumulated and compared with reliable records of yield and general observations of field and crop conditions extending over a number of years. The provisional lower limits of adequacy for West Indian cacao soils are presented in the following table:—

Provisional Lower Limits of Adequacy.

(West Indian Cacao Soils; Surface 6-ins. Layer).

	Sandy Soils.	Clay Soils.
Index of Texture (I.T.)	0-25	25-60
Organic Matter Content (per cent.)	3.0	4.0
Total Nitrogen Content (per cent.)	0.16	0.18
Carbon-Nitrogen Ratio* (C/N)	8.5	9.5
Available Phosphate (P_2O_5, p.p.m.)	30	50
Available Potash (K_2O, p.p.m.)	100	175
Degree of Acidity (pH value)	5.8	6.0

The system of marketing at present in vogue at the College particularly stresses natural organic matter content.† This component of unmanured cacao soils is the chief source of soil nutrients (nitrogen, phosphate and potash). In West Indian cacao soils, organic matter is mainly confined to the surface 6-ins. layer, which includes most of the "feeding-roots" of the cacao tree. Not only its total amount, but also its degree of decomposition or humification, as indicated by the magnitude of the carbon-nitrogen ratio, has been proved to be important in relation to fertility.

* M. Greenwood; private communication.

* For yields of over 400 lb. dry cacao per acre; planting distance, 12 × 12 feet.

† M. Greenwood (private communication) considers that the most important component of the Gold Coast cacao soils, and one whose magnitude may be taken as an Index of Fertility, is *organic matter*, largely because "it brings with it nutrients in a more-or-less balanced ratio". He suggests 1.0 per cent. as the lower limit of *carbon* content in the surface foot layer of "good" cacao soils. This corresponds to an organic matter content of 1.72 per cent. Usually the surface 6-ins. layer of cacao soil contains nearly three times as much organic matter as the second 6-ins. layer, so that the value 1.7 per cent. for the surface foot corresponds to 2.6 per cent. for the surface 6-ins., which should be compared with the value 3.0 per cent. accepted as the lower limit of organic matter content for fertile West Indian sandy cacao soils.

As regards mineral nutrition, the cacao tree appears to require relatively large amounts of potash (of the order of 150-200 p.p.m. exchangeable K_2O) ; hence the system of marking favours high potash content (30 per cent. of the total number of marks), especially in the case of sandy soils which are usually deficient in this nutrient. Phosphate is also apparently very important, especially because of its supposed significance in root development and nutrient absorption. Hence the system of marking also favours high available phosphate content (of the order of 40-60 p.p.m. (Truog) P_2O_5) ; 20 per cent. of the total marks are awarded to this nutrient factor.

The system evolved for West Indian cacao soils appears to apply satisfactorily in cases where the *water relations* of the tree are satisfactory, but it does not seem to apply in cases where soil structure is defective, and where the atmospheric environment of the tree is subject to rapid fluctuations in humidity, through inadequate protection from drying winds. The chief ecological moisture conditions favouring rapid growth and high production in cacao fields have been found to be (1) a constant and high water-supplying ability of the soil, and (2) a constant but relatively low evaporating-ability of the air. Environments in which these conditions do not obtain, even when soil nutrient factors are more-or-less satisfactory, appear from our experience not to be suitable to the best growth of cacao. Thus, badly-drained, compact and structureless soils, inadequately protected by wind-breaks and shade trees, and exposed to severe seasonal desiccation, fail to produce good cacao crops in Trinidad, and the application of manures, even when properly balanced, has been found not to raise the yield appreciably, so that the utilisation of such soils for cacao production is seldom economical.

Nutrient Assessment Gold Coast Cacao Soils.

In the accompanying table the Gold Coast profile sites are arranged in order of diminishing fertility, as gauged by the application of the marking system described in the last section. The age of the trees is also given, as well as relevant yield data ; the soil-type is indicated in the last column of the table. The profile sites are grouped into "good" (over 50 per cent. total marks), "medium" (50 to 35 per cent. marks), and "bad" (35 to 25 per cent.). Mean values are given for the data for each group. (*See* tables pp. 37-38.)

The most obvious feature of the table is the fact that "good," "medium" and "bad" soils are not strictly confined to any particular type of soil, and that many of the "bad" soils show truncated (or eroded) profiles. Evidently the parent rocks of the Gold Coast cacao soils do not differ very greatly (unlike those of Trinidad) in their value as soil forming materials.

The "good" soils have nearly neutral reaction, a mean organic matter content of approximately 3.5 per cent. (range, 1.8 to 5.3 per cent.), C/N ratios generally well over 10.0, large electrical conductivity values (indicating high nutrient status), and available phosphate and potash contents that are well over the lower limits of adequacy provisionally accepted for productive West Indian sandy cacao soils. At the other extreme, the "bad" soils are highly acidic, (more than ten times as acidic as the "good" soils), their organic matter contents are less than 2.0 per cent., their C/N ratios are less than 10.0 (indicating a high degree of decomposition and humification), and their nutrient status is very unsatisfactory. The "medium" soils show intermediate values. All the soils belong to the sandy category, but the "good" soils include the less sandy representatives.

A fair degree of correlation between laboratory assessment and actual yielding capacity is indicated in the table. While the mean yields of the "good" and the "medium" soils are nearly identical (about 700 lb. dry cacao per acre), the yield of the "bad" soils is about one-third lower (480 lb. ac.). Great variation is shown by individual yields within each group, and this cannot be attributed to variation in age. Several cases occur in which low yield is apparently associated with high fertility status, and contrarily, high yield with relatively low fertility status. Noteworthy examples of the first are No. 22 (Adawusina 2), No. 5 (Kumasi), No. 14 (Sesiamang), No. 7 (Asuansi 1), No. 18 (Kwabea) and No. 25 (Adiado), and of the second, No. 40 (Asuefu), No. 23 (Agogo) and No. 10 (Manhyia). Abstracts from the field notes appertaining to these sites indicate certain striking differences in the environment.

(A) Low Yield, High Fertility.

No. 22—(*Adawusina* 2) Rainfall, 65-70 ins. Site on raised ground, elevation 1,000 ft. Cacao trees rapidly dying ; leaves drooping. Normal over-head shade ; little ground shade ; secondary bush between trees recently removed. (Shallow soil, truncated by erosion) ; Yield, nil.

No. 5 (*Kumasi*)—Rainfall, 60-65 ins. Site at highest westerly point of Cadbury Hall Expt. Station. Condition of cacao trees, poor ; semideciduous ; many gaps. Ground shade, poor. Yield, 227 lb. ac.

No. 14 (*Sesiamang*)—Rainfall, 55-60 ins. Site on summit of low hill. No overhead shade ; moderate ground shade heavy attack by *Sahlbergella*. Yield, 500 lb. ac.

No. 7 (*Asuansi* 1)—Rainfall, 50-55 ins. Site on raised ground sloping to west. Site of Ashanti war camp. No shade trees, but good cacao canopy. Condition of trees, good. Yield, 304 lb. ac.

No. 18 (*Kwabea*)—Rainfall, 55-60 ins. Site on ridge in transitional belt between high forest land to west and savannah plains to east and north-east. No protection from wind ; devoid of shade ; signs of soil erosion ; land going into Secondary forest. Cacao trees dying out in patches. Yield 400 lb. ac.

GOLD COAST CACAO SOILS.

SITES ARRANGED IN ORDER OF LABORATORY ASSESSMENT.

(Summarised Data for Surface 6-ins Layer).

No. Site.	Sand Content %	Index of Text. I. T.	Reaction pH	Org. Matt. %	C/N Ratio	Avail. Nutr. mhos × 10-6	Rate of Soln. mhos × 10-6	Avail. P_2O_5 p.p.m.	Avail. K_2O p.p.m.	Age of Trees Yrs.	Yield of Cacao lb/ac.	Condition of Trees.	Soil Type.
1. Aburi	56	20	6.3	5.3	14.0	124	111	(324)	(341)	44	690	G.	RK
15. Samang	56	8	7.4	3.5	11.6	245	202	71	252	24	700	V.G.	RV
35. Sefwi Bekwai	(31)	(34)	6.9	4.7	9.7	148	200	(197)	122	17	900	V.G.	RBL
25. Adiado	53	15	7.6	3.7	10.0	279	320	50	127	3	Nil	G.	RK
18. Kwabea	78	3	7.1	2.1	9.5	245	115	58	268	32	400	P.	RV
19. Amoyu	65	7	6.5	4.3	10.8	204	185	41	185	18	890	G.	YAG
7. Asuansi 1	74	4	7.0	3.5	15.4	213	160	(174)	103	20	304	G.	YG
21. Adawusina 1	69	11	6.5	4.0	14.9	86	68	49	122	24	900	V.G.	YG
26. Amimle	70	4	6.9	2.1	13.3	118	80	43	189	29	1760	G.	YAK
6. Mbeim	(39)	27	6.6	3.8	11.8	162	235	26	(64)	22	800	G.	YBU
14. Sesiamang	72	5	7.1	2.5	10.8	165	113	26	103	22	500	G.	RV
13. Bukrum	75	6	7.3	3.6	10.1	223	149	26	(76)	27	700	V.G.	RV
39. Ntonso	76	7	6.7	1.8	10.9	113	73	19	(416)	28	940	F.	YG
Means ("Good")	60	10	6.9	3.4	11.7	179	154	41	163	24	702		
31. Konongo	60	10	7.0	2.2	9.2	106	122	20	92	30	1,700	G.	RBU
32. Bibiani	(39)	18	6.7	2.3	8.6	195	130	17	90	20	800	G.	RBL
28. Kpedze	58	16	5.7	2.9	10.3	104	84	19	77	?	910	F.	YK
5. Kumasi	66	8	5.8	2.6	11.2	59	26	19	90	26	227	V.P.	RBL
12. Nkawkaw 2	49	14	5.7	2.6	11.1	72	54	25	48	30	—	P.	YBU
11. Nkawkaw 1	49	12	5.8	1.1	8.9	95	108	21	79	19	—	F.	YBU
9. Nkawe	74	3	5.7	1.7	9.8	74	63	22	75	26	1,360	G.	YAG
22. *Adawusina* 2	67	9	4.6	2.3	10.9	75	17	27	89	21	Nil	P.	YG
27. Akome Agate	68	14	5.5	3.0	10.9	82	61	15	77	10	800	G.	YAK
29. Juansah	72	3	5.6	1.4	11.0	41	20	19	(138)	35	750	F.	YK
17. Cherechum	84	0	7.2	1.0	13.6	93	19	18	72	24	600	G.	RAK
37. Bompata 1	66	9	6.6	2.4	9.5	101	108	16	62	25	900	G.	RBU
3. Efiduasi 2	73	3	5.6	2.1	11.8	44	44	20	53	23	720	G.	YG
Means ("Medium")	66	9	6.0	2.1	10.5	88	66	20	75	24	713		
4. *Dotum*	49	12	5.6	1.5	7.6	58	64	24	45	21	490	F.	YAG
33. Wiawso	50	14	6.8	1.6	8.7	84	59	15	71	21	500	F	YBU
40. Asuefu	87	3	6.8	1.2	9.7	78	50	18	66	17	1815	F.G.	RV
23. *Agogo*	75	3	4.8	1.8	11.0	39	25	19	64	24	650	G.	RV
24. *Atasomanso*	67	6	5.1	1.6	9.3	46	34	24	65	17	Nil	V.P.	YBL
34. *Brofuyedru*	59	8	4.3	1.7	9.0	(129)	(0)	20	90	20	—	V.P.	YABL
10. *Manhyia*	88	0	5.7	1.2	10.7	62	72	21	39	20	710	F.G.	YBL
38. Bompata 2	79	4	6.1	1.7	9.9	52	53	15	51	34	400	V.P.	RBU
8. *Asuansi* 2	78	4	5.3	1.2	10.6	48	12	19	51	24	120	P.	YG
36. Adeiso	61	11	6.3	1.1	7.3	63	16	66	?	?	480	F.G.	YG
20. *Ampabami*	56	9	5.3	1.6	10.5	34	13	16	53	13	600	G.	YAG
30. *Juaso*	58	12	4.9	1.4	8.1	37	32	15	61	30	500	F.	RK
2. Efiduasi 1	78	1	6.3	1.0	9.8	40	30	16	57	25	516	P.	YAG
16. Okrakwajo	87	2	6.9	0.9	9.2	62	19	19	41	10	350	P.	YAK
Means ("Bad")	69	7	5.7	1.4	9.2	54	37	18	58	21	483		

NOTE.—Sites in *italics* type show *truncated* profiles.

SOIL TYPES:

Red Earth.	*Yellow Earth.*	*Alluvial (Yellow or Grey.)*	
RV	—	—	Voltaian.
RK	YK	YAK	Akwapimian ; Tarkwaian ; Archaean.
RBU	YBU	YABU	Upper Birrimian.
RBL	YBL	YABL	Lower Birrimian.
RG	YG	YAG	Granite.

GOLD COAST CACAO SOILS.—*Continued.*

FOR COMPARISON—SANDY CACAO SOILS OF BRITISH WEST INDIES.

	Sand Content %	Index of Text. I. T.	Reaction pH	Org. Matt. %	C/N Ratio	Avail. Nutr. mhos × 10-6	Rate of Soln. mhos × 10-6	Avail. P_2O_5 p.p.m.	Avail. K_2O p.p.m.	Age of Trees Yrs.	Yield of Cacao lb/ac.	Condition of Trees.	Soil Type.
TRINIDAD :													
Chocolate Soil	36	43	7.2	6.0	9.6	216	175	343	309	—	650	V.G.	—
Brasso Sand	60	18	6.2	2.5	7.8	100	87	39	267	—	450	G.	—
Moruga Sand	62	15	5.7	2.9	10.5	—	35	19	128	—	350	G.F.	—
TOBAGO :													
Schist Soil	—	35	6.7	4.8	10.2	180	177	82	87	—	450	G.	—
Diorite Soil	—	39	6.4	4.7	10.2	175	160	30	94	—	450	G.	—
Alluvium	—	29	6.5	4.1	12.0	180	173	75	80	—	550	V.G.	—
GRENADA :													
Basic Igeous....	—	40	6.9	3.7	10.7	135	117	85	380	—	600	V.G.	—

LIMITS OF ADEQUACY—(Provisional Trinidad Standards).

Sandy Cacao Soils :—Avail. Phosphate (P_2O_5) 30 p.p.m.
Avail. Potash (K_2O) 100 p.p.m.
C/N Ratio (Yields of 400 lb. or over per acre) 8.5 to 11.0.

No. 25 (*Adiado*)—Rainfall, 55-60 ins. Site on gently-sloping land. Over-head shade provided by sparse Oil Palm ; good ground shade by weeds. First two plantings failed, 1921, 1928. Drought suggested as chief cause of die-back. (Soil one of highest nutrient status.) Yield, nil, but trees only 3 years old.

(B) HIGH YIELD, LOW FERTILITY.

No. 40 (*Asuefu*)—Rainfall, 70-75 ins. Site on sloping ground sheltered by 1,000 ft. scarp Medium over-head shade; good ground shade. Yield, 1,815 lb. ac.

No. 23 (*Agogo*)—Rainfall, 70-75 ins. Site on raised ground, sloping gently to south-east. Over-head shade, sparse ; adequate ground shade. Cacao trees in good condition. Yield, 650 lb. ac.

No. 10 (*Manhyia*)—Rainfall, 60-65 ins. Site on gentle slope to east, small stream 100 yds. distant. Over-head shade, good ; ground shade, fairly good ; cacao trees, fairly vigorous. Yield, 710 lb. ac.

It will be noticed that the *low-yielding* sites on soils having high nutrient status occur in regions of relatively low rainfall (55 to 60 ins., in all but one case) ; they generally occupy exposed, elevated ground, deficient in overhead shade and ground shade, while the *high-yielding* sites on poorer soils all occur in regions of higher rainfall (60 to 75 ins.), and occupy gently-sloping ground, generally well provided with overhead shelter and adequate ground shade. Thus environmental water relations seem to play a very important part in deciding the productivity of the sites ; "good" soils situated in environments whose water relations are unsatisfactory (because of inadequate rainfall, unsuitable topography or a very open soil structure) fail to support vigorous and fruitful trees, while "poor" soils situated in environments having highly satisfactory water relations may produce fairly good crops, in spite of a relatively low nutrient-supplying ability of the soil.

One of the chief axioms of crop ecology stresses the advantages of selecting the most suitable soil and atmospheric environment for planting a particular crop, rather than attempting to modify an unsuitable environment to the crop's needs. In practice, economic considerations ultimately decide the choice, for when profits are high, the second procedure may be admissible, but when profits dwindle, the advantage obviously lies with the first selection. The truth of this axiom has been clearly revealed by Prof. Shephard in the case of the cacao crop in Trinidad, and the demonstration was possible by virtue of the accumulated information previously gained through ecological investigations of the cacao tree growing in widely divergent environments associated with distinctive types of soil and topography.

DIE-BACK OF CACAO IN THE GOLD COAST.*

A wide-spread incidence of cacao failure in the Gold Coast was investigated in 1934 by Mr. Greenwood at Nankesi, near Koforidua, Eastern Province, where the crop is grown on Yellow Earth soil derived from Cape Coast Granite. Numerous cases of "die-back" had been observed in patches of 20-year old trees, especially during a severe drought in January 1930,

*Unpublished typescript report; M. Greenwood, 1935.

Condition of Trees.	No. of Soil Samples	Sand Content %	Reaction pH	Org. Matter %	C/N Ratio	Avail. Nutr. mhos × 10-6	Rate of Soln. mhos × 10-6	Avail. Phosphate (P_2O_5) p.p.m	Avail. Potash (K_2O) p.p.m
Healthy	15	79	(6.7)*	2.9	12.6	187	260	29	—
Die-back	15	78	(6.8)*	2.5	12.2	164	268	24	—
Present Survey	10	69	6.0	2.5	11.0	63	38	26	69

* Colorimetric method.

when the rainfall was only about one-third of the month's average for the previous ten years. Notes were made on the environmental conditions within contrasted "healthy" and "die-back" groups of cacao trees, occurring in seven different farms, and representative soil samples were collected for laboratory examination. The soil data are summarised in the above table for the surface 6-ins. layer,in which they are compared with results for the ten Cape Coast granite soils examined in the present investigation.

It will be noticed that no significant differences (except perhaps in organic matter content) distinguish the "die-back" soils from the "healthy", and that the range of soils examined is similar in nutrient status to the typical Cape Coast Granite soils of the Colony. On the other hand, the degree of shade and of exposure to light and wind was observed to differ greatly in the contrasted sites. In general, both the ground and overhead shade of the trees showing die-back was scanty, or the "bad" sites occupied hill crests exposed to drying winds, or the soil was subject to waterlogging. The die-back condition seemed to have spread in most cases from gaps in the foliage canopy caused by the removal of shade trees, timber trees or Oil Palms, or the clearing of land for the planting of provisions or the extension of housing. The surface soil is sandy, and layers of quartz gravel and ironstone concretions are conspicuous in the upper part of the profile, so that upward movement of water from the underlying clay subsoil is probably restricted. The depth of the gravel layer at the "good" sites was found to be noticeably greater than at the "bad" sites (average depths, 20 as against 11 inches). No measurements of soil moisture nor of atmospheric humidity were made, but it is concluded from the general evidence that the main causes of cacao die-back in the Nankesi area are a rapid drying-out of the soil and a greater degree of atmospheric desiccation within the sites occupied by the affected trees, induced by interference with shade and the occurrence of a shallow sandy type of soil.

From these considerations, it is evident that cacao soil studies in the Gold Coast should be accompanied by ecological investigations of the environment. Laboratory analysis of soil samples alone cannot be expected to explain causes of failure, nor to reveal significant differences between sites of high and low productivity. Methods whereby fluctuations in soil and atmospheric environments may periodically be measured have been evolved and successfully applied in similar cases in Trinidad, and it is suggested that these procedures might be followed in West Africa.

(VI) Summary.

(1) This report is a continuation of a discussion of laboratory results and field information appertaining to a collection of 400 samples of soil representing 40 profiles exposed at selected sites within the Gold Coast cacao belt.

(2) The profiles have been classified in accordance with the geological formations from which corresponding soil-types have been derived. In all, 15 soil-types have tentatively been identified, but of these, five are Alluvial types (11 profiles) and not very distinctive. The remaining 10 soil-types are sub-divided into sedentary Red Earths and Yellow Earths, solely on the general appearance of the profile down to the six-foot depth. The red soils have been derived from a sedimentary formation (Voltaian ; 6 profiles) and from four metamorphic rock formations (Akwapimian, Tarkwaian and Upper and Lower Birrimian ; 9 profiles). The yellow soils have been derived from acid intrusive rock (Cape Coast Granite ; 7 profiles), and from the same kinds of metamorphic rocks (7 profiles) that have produced the red soils, although variations between yellow and red metamorphic rock soils have been noted.

(3) The occurrence of erosion, which truncates the profile in certain cases, has been indicated, and its effects on soil productivity have been discussed.

(4) Additional notes on the main soil-types are submitted, and probable causes of colour variation have been cited.

(5) An attempt has been made to assess the fertility of the soils in terms of laboratory data for the surface 6-ins. layer of each of the 40 profiles, by an arbitrary system of marking. The apparent order of fertility is compared with actual yield data, expressed as lb. dry cacao per acre, and with the age of the trees. Although a general correlation between nutrient status and yield has thus been revealed, factors such as situation, rainfall, exposure to winds and degree of shelter and shade, appear to play an important part in

their effects on the water relations of the tree, and indirectly on the nutrient status of the soil, insofar as they may have been responsible for soil erosion or profile truncation.

(6) No distinctive profile characters that could be attributed to specific mineralogical differences between the parent soil-forming rocks have been discovered, so that differences in nutrient status must be referred to the pedological history of the profile sites.

(7) The need of detailed ecological environmental studies of the cacao tree in the Gold Coast is urged as an accompaniment to laboratory soil investigations.

Acknowledgment.

Much of the subject matter of this article was provided by Mr. M. Greenwood, Chemist of the Gold Coast Department of Agriculture, without whose co-operation the work could not have been accomplished.

MANURIAL EXPERIMENTS ON CACAO IN TRINIDAD: SUMMARY OF RESULTS FOR 1937.

By F. Hardy.

In the last Annual Report on Cacao Research (Sixth Report, 1936, pp. 24-34), an account was given of manurial experiments on cacao initiated in Trinidad in 1932 by J. A. McDonald (formerly Chemist for Cacao Research), and carried on by him up to the end of 1935. The review included also a description of a few additional experiments, as well as of the continuation of the initial series, carried out under the *aegis* of the Cacao Relief Scheme during 1936, by F. J. Pound (Agronomist of the Department of Agriculture of Trinidad and Tobago). The following account concerns the results for the year 1937; it forms a summary of information published elsewhere by F. J. Pound, or privately communicated. The writer wishes to express his indebtedness to the Director of Agriculture and to Dr. Pound for permission to issue these results in their present form.

Certain innovations have been introduced into the present report, namely:

(1) As far as possible, detailed tables of yield data are omitted, and the main results only are stated. It is thought that this procedure will give greater clarity to the subject matter; the kinds of lay-out, the actual yields, statistical tabulations and calculations are available in the Progress Reports prepared by F. J. Pound for the Cacao Subsidy Board, and it is unnecessary to duplicate them here.

(2) Instead of recording results in various units, which make it difficult to compare manurial responses and the effects of natural soil fertility, all relevant data have been standardised in terms of *pounds weight of dry cacao per acre* of land, which is the unit most favoured by investigators, not only in Trinidad, but also in West Africa. In Trinidad and Tobago, the standard practical weight unit of dry cacao is the bag of 165 lb. This larger unit has also occasionally been used. Many planters prefer to express yields in bags of dry cacao per 1000 trees or "pickets", but, unless the spacing distance of the trees is known, it is impossible to convert these quantities into pounds per acre.

(3) Instead of classifying the experiments primarily into manurial types (such as Phosphate Series, General Manure Series, Organic Manure Series, &c.), it is proposed to describe them as far as possible under soil-types, using the term in a broad sense only, pending the publication of detailed soil maps and type descriptions, which will be forthcoming when the soil survey of Trinidad and Tobago, now being conducted by E. M. Chenery, is complete.

(4) The original system of nomenclature and numbering has been altered somewhat. Originally, the manurial experiments were numbered in the order in which they were laid down, and named after the estate where they were situated. Since the experiments were taken over by the Department of Agriculture, they have been given separate code letters, indicating, not only the type of lay-out (Type A, Latin Square; Type B, Acre Block, as well as special cultivation, pruning, budding, estate-manuring and rehabilitation estate experiments), and also special code numbers, indicating the order of initiation.

By the end of the year 1937, forty-four (44) Type A (Latin Square) manurial experiments of different sorts, and 160 or more Type B (Acre Block) experiments were in being, as well as a large number of planters' experiments.

The present report concerns Type A experiments only, though it is unnecessary to consider all of them, since most have given only one year's records, few of which are conclusive, partly because of the abnormal weather conditions that prevailed during 1937.

(I) Acidic Alluvial Clays of River Vegas and Basins of the Northern Plain of Trinidad.

The area where this soil-type occurs is covered by Sheet E of the Cadastral Survey. It includes the Sangre Grande Alluvial Basin, and the narrow riverain strips ("vegas") bordering water-courses that originate either in the Northern Range or in the Central Range of uplands. Cacao yields during recent years have diminished considerably

in this area, and it is imperative that the ecological conditions of soil and climate should be intensively studied with a view to prescribing means for improving the general growth conditions.

The first manurial experiments laid down by J. A. McDonald in 1932 were the direct outcome of our ecological studies of two contrasted cacao plots, of which one (the " bad " plot) was situated on a clayey river vega at Las Hermanas Estate, San Rafael. Here the soil was found by chemical tests to be very deficient in available phosphate. The following experiments have yielded much information regarding the manurial and agricultural needs of this soil-type.

(1) *Las Hermanas I.*—(Code A2) 1932-1937. (*See* p. 26, Sixth Rept.)

Over a period of four successive years, trees treated with 3, 2 and 1 lb. of superhosphate here gave average annual yield increases of 73.2, 33.5 and 45.5 per cent. respectively, as compared with trees not manured. In 1937, no more superphosphate was applied but still the yields showed increases due to the *residual effects* of the previous treatments, namely, 59.3, 28.0 and 43.3 per cent. of the yield of the unmanured trees. Thus, at the present stage, the results show that the smallest application (1 lb. superphosphate per tree) was the most economical dressing, since, with cacao worth 3.4 cents per lb. in the field, or 4.6 cents per lb. in Port-of-Spain, this application would be profitable. The yielding capacity of the soil of the unmanured plots averaged 250 lb. dry cacao per acre of 300 trees or 1.5 bags per acre, but the trees comprising the different plots were initially selected, gaps and damaged trees being eliminated from the experiment.

(2) *Las Hermanas II* (Code A3) 1934-1937. (*See* pp. 26-27, Sixth Rept.)

The last experiment demonstrates the value of phosphatic manure applied to cacao growing in this acidic alluvial clay. The next experiment was designed to compare two different kinds of phosphatic manure, namely, ground rock phosphate and superphosphate.

So far, superphosphate (which is a soluble manure) has given greater yields than the insoluble rock phosphate, but last year (1937), the difference was not so great. Potassium sulphate manure was also applied in this experiment as a half-plot treatment, and its addition seems to confer some benefit, though its effect so far has not been statistically significant.

Data for yields, corrected to equalise the effects of the initial natural yields of the trees, and expressed as percentage increases over the unmanured trees, are given by Pound in Table I. The yielding capacity of the soil of the unmanured plot averaged only 196 lb. dry cacao per acre of 300 trees, or 1.2 bags per acre, while that of the soil manured with superphosphate gave 308 lb. per acre or 1.9 bags, and with superphosphate and potash 343 lb. per acre (2.1 bags).

Table. I.

Comparison of Soluble and Insoluble Phosphatic Manures on Acidic Alluvial Clay: Las Hermanas Estate.

Treatment	1935.	1936.	1937.
	Per cent. Increase in Yield.		
Superphosphate	52.7	50.0	68.4
Superphosphate *plus* Potash....	76.4	62.1	86.3
Ground Rock Phosphate	34.6	45.5	66.1
Ground Phosphate *plus* Potash	52.6	66.7	66.0

In the long-run, ground rock phosphate may be as effective as superphosphate, but with cacao valued at less than 6.2 cents per lb. in the field, the use of superphosphate would not be profitable at this site, nor ground rock phosphate profitable at prices less than 10.8 cents per lb.

(3) *Las Hermanas III* (Code A4) 1936-1937. (*See* pp. 27-29, Sixth Rept.)

In this experiment, further comparison is made between superphosphate and ground rock phosphate, as well as with ammonium phosphate ("Nicifos") and double superphosphate, both highly soluble forms of phosphatic manure. The 1937 results are somewhat different from those obtained in 1936. They demonstrate that, whereas insoluble rock phosphate still gives the lowest increments in yield, there is now no significant difference between the effects of the three *soluble* phosphatic manures. The nitrogen contained in the ammonium phosphate manure again provided no benefit, nor did potash manure superimposed on phosphate. The most economical treatment was superphosphate, but, when cacao is worth less than 7.1 cents per lb. in the field, it would not be profitable at this site. Here again, however, the yielding capacity of the soil of the unmanured plot only averaged 263 lb. dry cacao per acre of 300 trees, (1.6 bags), while that of the best manured plot was 392 lb. (2.4 bags) per acre.

Limiting Factors:—Although chemical tests show that this acidic alluvial clay soil-type of the Northern Plain vegas is deficient in available phosphate, and that phosphatic manures give marked increases in yield, the productivity of the soil, even when treated with the most effective manures, is still very low (less than 3 lb. of wet cacao per tree, or 320 lb. of *dry* cacao per acre of 300 trees, or 1.9 bags per acre). Nor is the yield materially improved by treatment with potash manures nor with nitrogenous manures, the latter even depressing yields somewhat. Evidently some other deleterious factor or factors are operating to limit cacao yields, and these require investigating experimentally. It is suggested that chief among these limiting factors is inadequate soil aeration, which in turn, is due to marked deterioration of soil structure.

(II) Acidic Alluvial Sands and Silts of River Vegas of the Northern Range Valleys.

Many of the river valleys within the Northern Range of Trinidad are occupied by alluvial flats, but their magnitude diminishes eastwards. Thus rivers lying to the east of the Arima River have not yet attained their base level of erosion, and their valleys contain little or no alluvium, except where they debouch onto the Northern Plain. The alluvial soil is usually sandy or silty, having been derived from various kinds of metamorphic rocks, (mainly sandy quartzose schists) that comprise the mountain range. One of the most extensive of these alluvial areas is that occupying the Diego Martin Valley west of Port-of-Spain, in which River Estate is situated.

Preliminary manurial experiments conducted on Northern Range sandy alluvium during 1932 to 1936, demonstrated that this type of soil may show appreciable responses to phosphatic manuring, but that it shows even more striking responses to potash manuring, as for example at River Estate.

The following two experiments, laid down in 1934, were designed to compare the relative effects of potash, phosphate and nitrogen on acidic silty alluvial soil at River Estate, on cacao growing both under normal shade and unshaded by Immortel trees.

(1) *River Estate II.* (Code A12). *Normal Shade*, 1934-1937. (*See* pp.28-30, Sixth Rept.)

(2) *River Estate III.* (Code A11). *No Shade*, 1934-1937 (*ibid.*).

During the first two years of these experiments (1934-1936), greatest increase in yield due to manuring was given by the *shaded* plots. This result was unexpected, because it was thought that shade trees might take up a large part of the added manures. In each case, however, large increases in yield, of the order of 53 per cent., were given by manures including potash. The results of the last year (1937) substantiate those of the previous two years. The following table (Table II), adapted from that published by Pound, shows the differences to date between the yields of the shaded and the unshaded trees, and the effects of the different manurial treatments, as contrasted with the natural yields at the beginning of the 3-years' experiment.

The *unmanured* soil of the control plots gave an average initial yield of about 500 lb. (3.0 bags) of dry cacao per acre of 300 trees, which increased naturally during the course of the experiment by an average annual amount of 371 lb. (2.3 bags), or 74 per cent., while the *best manurial treatment* (NP_2K), rich in potash, gave average annual increases of 825 and 770 lb. dry cacao per acre for the shaded and unshaded plots respectively. Thus, manuring the shaded trees gave an increase of 51 per cent. over the yield of the unmanured trees, and manuring the unshaded trees gave an increase of 41 per cent. The superiority of manures containing potash over those containing nitrogen and phosphate is clearly shown by the data in the table.

(3) *River Estate V.* (Code A14). 1936-1937. (*See* p. 31, Sixth Rept.)

This experiment was designed to test the effect on the benefit known to accrue from potash manuring acidic river alluvial silty soil, of nitrogenous and phosphatic manures superimposed on the potash treatments. Both sulphate and muriate (chloride) of potash were applied in two series of plots. The nitrogenous manures comprised ammonium sulphate and ammonium phosphate ("Nicifos C"), while the phosphatic manures comprised "Nicifos" and superphosphate, each in equivalent quantity. The yield data are given in Table III, adapted from Pound's report.

Table II.

Effect of Manures on Shaded and Unshaded Cacao : River Estate.

Treatment.	Initial Natural Yields		Average Increases per Annum		Average Increases over Control		Difference due to Shading
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded	
	Lb. ac. Dry Cacao		Lb. ac. Dry Cacao.		Lb. ac. Dry Cacao.		Lb. ac. Dry Cacao.
N	442	519	407	491	35	121	−86
P	429	385	519	378	147	8	+141
K	286	486	653	517	281	147	+134
NP	359	480	(708)	315	(336)	−55	(+391)
NK	367	440	631	623	259	253	+ 6
PK	396	438	783	592	411	222	+189
NPK	449	495	697	581	325	211	+114
NP_2K	444	510	825	770	453	400	+ 58
Control	469	539	372	370	—	—	—

Table III.

EFFECT OF NITROGENOUS AND PHOSPHATIC MANURES ON POTASH-MANURED ALLUVIAL SILT—RIVER ESTATE.

Treatment.		Yields. [lb. Dry Cacao per Acre (300 Trees.)]			Per cent. Increase over Control.
		1936.	1937.	Average Annual Yield	
Sulphate of Ammonia	+Sulph. of Potash	898	880	889	1.2
	+Muriate of Potash	933	981	957	
"Nicifos C"	+Sulph. of Potash	979	1,010	994	11.3
	+Muriate of Potash	939	1,133	1,036	
Superphosphate	+Sulph. of Potash	1,067	1,115	1,091	22.3
	+Muriate of Potash	1,133	1,148	1,140	
Sulph. of Amm.+Super	+Sulph. of Potash	878	1,010	944	−5.5
	+Muriate of Potash	761	801	781	
Control (Sulph. of Potash)		889	948	918	—
Control (Muriate of Potash)		898	915	906	

The average annual yield of the unmanured trees for three years before the experiment was started was 510 lb. of dry cacao (3.1 bags) per acre of 300 trees (12×12 ft.). The yield of plots which received potash only was 912 lb. (or 3.5 bags) per acre, and of plots which received potash and superphosphate, 1,115 lb. (6.8 bags) of dry cacao per acre. These yields are extremely high for Trinidad (3½ bags per acre being an average high value), and the data for manured plots indicate the great benefits that may accrue from manuring this type of soil with appropriate manures, including both potash and phosphate, but especially potash.

In this experiment, sulphate and muriate of potash both gave similar increments, so that presumably the cheaper muriate might be used with the same advantage as sulphate. Evidently phosphatic manures may augment the yield when potash is not the limiting factor. Ammonium sulphate proved to have no value whatsoever in this experiment, and "Nicifos C" showed less value than superphosphate.

(4) *River Estate V I.* (Code A1) 1934-1937. (*See* pp. 32-33, Sixth Rept.)

This experiment was initiated by the Botanical Section of Cacao Research as a complete field test of the interactions between nitrogen, phosphate and potash manures, used both alone and in different combinations, on normally-shaded cacao growing in acidic, sandy-loam, river alluvial soil. The yields were recorded as numbers of cacao pods, so that it is not possible to express accurately the yielding capacity of the manured and unmanured soil in terms of weight of cacao per acre. Records show, however, that the soil of the unmanured plots yielded at the rate of about 600 lb. (or 3.6 bags) dry cacao per acre of 300 trees.

The control plot decreased in yield during the first three years of the experiment by 17.3 per cent. (number of pods). The superphosphate-treated plots also decreased by 16.8 per cent., while plots treated with ammonium sulphate, either alone or mixed with superphosphate or with potassium sulphate, showed about the same change as the control plots. The only treatments that gave increased yields in this experiment were (*a*) potash manure (*b*) potash and superphosphate, and (*c*) potash, superphosphate and ammonium sulphate, each of which produced an increase of nearly 50 per cent. in number of pods over those produced by the unmanured soil.

No manures were applied in 1937, but yields were again determined in order to assess the *residual effects* of the previous manurial treatments. The records for this year still show much lower yields for all plots than the initial natural yields for 1931-1932. While the control plots show a total *decline* in yield of 43.8 per cent. for the "residual" year, those manured with ammonium sulphate show an even greater decline (55.5 per cent.), but those manured with superphosphate show no additional decline. On the other hand, plots manured with potassium sulphate show a decline of only 12.2 per cent. as compared with 43.8 per cent. for the control plots, thus demonstrating a marked residual effect due to potash. Where potash manure was added along with ammonium sulphate or superphosphate, the decline associated with these two manures applied alone has been arrested, and amounts only to 23.0 per cent., as compared with 43.8 per cent. for the manured soil. Hence the only beneficial manure has been potassium sulphate, whose addition, over a period of three years, has built up an appreciable reserve of available potash in the soil.

At the end of three years, a profit of $3.23 per bag (165 lb.) increase of dry cacao was realised with cacao worth 6 cents a pound, or $9.83 if worth 10 cents a pound. The cost of producing one bag increase at current prices of manures was $6.67, but this is now reduced to $6.15 by the realisation of the residual manurial effects during the fourth year of the experiment.

(5) *River Estate VII, VIII and IX.* (Code A8, A9, A10). 1935-1937.

These three new experiments, which may be considered together, were designed to ascertain the effects of increasing doses of potash manure on acidic sandy-loam river alluvial soil that had been treated in different ways, as follows:— (1) normal; no additions or extra treatments, (2) soil limed at the rate of 5 tons of ground limestone per acre, (3) soil treated with a basic dressing of superphosphate at the rate of 2 lb. per tree, (4) soil limed and treated with superphosphate, and (5) soil previously "trenched" with organic materials, according to the customary practice adopted at River Estate for disposal of waste vegetation by burying in the drains. The following yields during the first year were obtained (Table IV), the figures being based on data contained in Pound's report.

The untreated soil in these experiments gave a natural yield of about 600 lb. (3.6 bags) of dry cacao per acre of 300 trees. Liming had no significant effect on yields, nor had superphosphate alone, or in combination with lime. Trenching alone usually gives yields of about 700 lb. of dry cacao per acre on this soil-type. The largest yield (1,008 lb. ac.) was given by potash manure (2 lb.) in combination with superphosphate (2 lb.). This represents an increase of about 85 per cent. over the yield of the control plots. Lime in addition to potash and superphosphate slightly depressed the yields. Potash (2 or 3lb. per tree) augmented (by about 36 per cent.) the beneficial effects of trenching.

These results particularly indicate the value of superphosphate applied in combination with potash on this soil-type, whose primary deficiency is potash, though phosphate appears also to be somewhat deficient by chemical tests.

(6) *River Estate X.* (Code A18). 1937.

In another recent experiment, potash manure applied to plots that had just previously been trenched, gave 40.7 per cent. increase in yield control, 540 lb. (3.2 bags) dry cacao per acre of 300 trees, and potash manured soil, 760 lb. (4.6 bags per acre), while superphosphate gave 11 per cent. increase (548 lb. ac.), and potash *plus* phosphate gave 13.5 per cent. increase (613 lb. ac.). These are first year's results, and no final conclusions are yet forthcoming.

(7) *River Estate IV.* (Code A13). 1931-1936. (*See* pp. 30-31, Sixth Rept.)

This is a *mulching* experiment, designed to test the effect of spreading waste vegetable matter over the soil, and the additional effects of adding to it ammonium sulphate, superphosphate and potassium sulphate, both singly and in various combinations. The soil is typical of the acidic silty river alluvium of River Estate. Altogether there are 15 different treatments. The *natural yields* of the trees prior to the application of manures, and the experimental yields for the manured plots after two years' treatment (1934, 1935), are given in the Sixth Annual Report, and no further data are yet forthcoming.

The only dressings that gave appreciable increases in yield were (1) potash *plus* phosphate (38.1 per cent.), (2) the same *plus* mulch (36.5 per cent.), (3) potash *plus* mulch (27.5 per cent.) and (4) phosphate *plus* mulch (21.3 per cent.). *Mulch alone gave no increase,* but it greatly augmented the beneficial effects of potash and phosphate when applied in addition, whereas ammonium sulphate *reduced* these effects. Hence it is apparently not the nitrogen contained in pen manure and other organic manures that is their main virtue, as cacao manures but rather their content of potash (and phosphate), as well as perhaps their energy-supplying carbohydrates.

The yield of the unmanured soil in this experiment was 513 lb. (3.1 bags) dry cacao per acre of 300 trees, and of the soil manured with potash and phosphate, 708 lb. (4.3 bags) per acre, an increase of 38 per cent.

(8) *River Estate XI.* (Code A19). 1937.

This is another new (organic manure) experiment, designed to compare different methods of applying *pen manure* to acidic sandy alluvial soil. The pen manure was applied either as (1) a surface dressing, (2) forked into the soil, or (3) buried in trenches. So far, forked-in pen

Table IV.

Optimum Potash on Variously-Treated Soil; River Estate.

Potash Manure (Dressing per tree).	Lb. Weight Dry Cacao per Acre.					
	No. Extra Treatment.	Lime.	Super-phosphate.	Lime+ Super-phate.	Trenched.	Averages.
Control	576	542	564	600	703	597
1 lb.	590	776	752	818	680	723
2 lb.	744	(730)	1,008	898	835	843
3 lb.	724	689	992	928	953	857
Averages	658	684	829	811	793	—

Table V.

TRENCHING WITH AND WITHOUT ARTIFICIAL MANURES AND LIME—RIVER ESTATE.

Treatment.	(LB. DRY CACAO PER ACRE.) Control (No Treatment).	Trenched with Pen Manure.	Potash and Phosphate Artificial Manures.	Trenched and Artificial Manures.	Means.
With Lime	493	650	701	818	666
Without Lime	581	630	748	745	676
Averages	537	640	724	781	671

manure has given the largest increases in yield (48 per cent.), and the surface dressings the next largest (34 per cent.), while trenching has given least response (18 per cent.), though it is too early to draw final conclusions. The unmanured soil gave 473 lb. (2.9 bags) of dry cacao per acre of 300 trees, while the forked-in pen manure treatment gave 700 lb. (4.2 bags) per acre, an increase of 48.0 per cent. The beneficial effects of surface dressings might not be lasting; they may induce superficial rooting, and the trees may suffer during periods of drought.

(9) *River Estate X I I.* (Code A20). 1937.

A second pen manure experiment was designed to test the value of trenching, both with and without the application of a mixture of sulphate of potash and superphosphate, with ground limestone superimposed in a half-plot treatment. The first year's results are contained in the following table (Table V), adapted from Pound's report.

Evidently liming has conferred no benefit in this experiment, and artificial manures have so far proved more beneficial than trenching, though both together have given the highest yield, namely an average of 781 lb. (4.7 bags) of dry cacao per acre of 300 trees, for a soil whose natural yielding capacity is about 537 lb. (3.2 bags) per acre, an increase of 45.4 per cent.

(III) Neutral, Sedentary Black Clays of the Naparima District, South Trinidad: Princes Town Marl Soil Type.

This distinctive "humus-carbonate" type of soil occurs as a series of narrow belts, running E.N.E. to W.S.W. across the Southern Plain of Trinidad, practically from coast to coast. It includes some of the best sugar-cane lands of the Ste. Madeleine Company, as well as productive cacao lands in the Princes Town-Rio Claro area. Its main features were described in the fourth Annual Report, pp. 51-53. The parent rock is a nodular pale-grey marlstone, usually containing over 35 per cent. of calcium carbonate. It is relatively rich in potash-bearing minerals, but very deficient in phosphate. The soil is a neutral heavy black clay to a depth of about 10 inches, changing suddenly to a cream-coloured marly subsoil, whose carbonate content increases rapidly below an average depth of 24 inches. Organic matter and nitrogen contents and available potash are high in amount, but available phosphate content is generally very low (17 p. p. m.). The structure of the surface soil is usually crumbly, owing to the high calcium status, and natural drainage and aeration are good. In these respects, the soil differs fundamentally from the acidic alluvial clays of the Northern Plain vegas. The following manurial experiments have given striking results on this soil-type.

(1) *Rio Claro I I I.* (Code A5, A6). 1936-1937. (*See* p. 28, Sixth Rept.)

A preliminary experiment (1932-1935), carried out on Princes Town Marl Soil, demonstrated that very large and profitable benefits follow the application of superphosphate. Initial increases in yield of over 100 per cent. were obtained with applications of this manure at the rate of 1½ lb per tree.

The experiment under consideration was designed to compare superphosphate, ammonium phosphate ("Nicifos A"), double superphosphate and ground rock phosphate, applied in equivalent dressings. During the first year (1936), superphosphate, 3 lb. per tree, gave an *increase* in yield of 257 lb. dry cacao, or 1.56 bags per acre, while the unmanured plots gave a yield of about 346 lb. dry cacao, or 2.1 bags an acre of 224 trees. This represents a 74 per cent. increase due to superphosphate manuring, and the profit, exclusive of carting and fermenting, would be about $10 an acre, with cacao selling at 6 cents per pound. Double superphosphate gave the next highest increase, namely, 41 per cent.; ammonium phosphate ("Nicifos") gave 35 per cent., while rock phosphate gave only 11 per cent. increase. Actually, the field in which this experiment was situated yielded at the time only about 140 lb. dry cacao, or 0.9 bag, per acre of 224 trees. The trees comprising the experimental plots were specially selected, some 20 per cent. of the tree population thus being eliminated as "poor bearers".

Muriate of potash, superimposed in half-plot treatments, gave no additional response, presumably because the soil contains adequate available potash (154 p.p.m. K_2O), according to chemical

tests. During the past year (1937), the increases were 44, 30, 16 and 9 per cent. for the respective manures, the reduction in yields being attributed to an unfavourable growing season.

Gypsum Effect.

The reason why superphosphate has so far always given the greatest responses in this experiment, and alone has proved profitable at current cacao prices, is difficult to explain. Usually, soils containing calcium sulphate (gypsum) (say, over 500 parts $CaSO_4$ per million of soil), such as gypseous Brasso Clay soil, produce only very poor crops of cacao in Trinidad. Superphosphate contains 60 per cent. by weight of calcium sulphate, so that a dressing of 3 lb. per tree (equivalent to 672 lb. per acre in this experiment), would impart a gypsum content of about 200 p.p.m. to the surface 6-inch layer of soil, and continuous applications of the manure might, in time bring about a harmful accumulation of the substance. To test this possibility, a special gypsum experiment was laid down on neutral black marl soil at Rio Claro. It is described in the following section.

(2) *Rio Claro IV.* (Code A7.) 1935-1937. (*See* pp. 31-32, Sixth Rept.)

Gypsum was applied at the rate of 6 lb. per tree, both alone and together with superphosphate (4 lb. per tree), and tested against double superphosphate (2 lb. per tree), which contains no gypsum. Yield results for two consecutive years are given in the accompanying table (Table VI), adapted from Pound's report. The yielding capacity of the soil of the untreated plot averaged 300 lb. (1.82 bags) of dry cacao per acre of 224 trees, while that of the plot manured with superphosphate was 405 lb. (2.45 bags) of dry cacao per acre.

Although the amount of gypsum introduced into the soil is well above the suggested limit of tolerance (500 p.p.m.), the detrimental effect on yield so far is very small. It should be noted, however, that the original soil was neutral in reaction (pH 7.1), and belongs to quite a different type from "bad" Brasso Clay soil (an unresponsive gypseous soil-type), so that the test is probably invalid. The experiment should be continued, and a similar trial should be applied to an acidic non-calcareous soil-type, such as alluvial clay.

The above descriptions of seventeen (17) manurial experiments now in being on three of the most important nutrient-deficient soil-types occurring in Trinidad, do not include all the Type A (Latin Square) experiments laid down up to the end of 1937 by F. J. Pound; there are actually forty-four (44) Type A experiments in all, and they are distributed among eight distinct types of soil, including the three important types already mentioned. The soil-types so far considered may provisionally be classified and named as follows:—

Trinidad.

(A) Northern Range.
  (1) *Acidic Alluvial Sands and Silts of River Valleys.* **A1, 8, 9, 10, 11, 12, 13, 14,** 15, **18, 19, 20,** 35, 40, 42, 43.

(B) Northern Plain (Sangre Grande-Manzanilla District).
  (2) *Acidic Alluvial Clays of River Vegas and Basins.* **A2, 3, 4,** 16, 17, 25, 26, 27, 30, 31, 38, 39, 41.
  (3) *Talparo Acidic Red Clay.* A28, 29.

(C) Central Range (Montserrat District).
  (4) *Brasso Clay.* A34.

(D) Southern Plain (Naparima District).
  (5) *Princes Town Marl Neutral Black Clay.* **A5, 6, 7,** 21, 36.
  (6) *Acidic Alluvial Clays* (Guapo). A32, 33, 44.

(E) Southern Range (Siparia-Penal-Moruga Districts).
  (7) *Moruga Sand.* A37.

Tobago.

(F) Southern Slopes.
  (8) *Igneous Rock of Alluvial Derivatives.* A22, 23, 24.

The numbers in this table are the Type (A) code numbers of cacao manurial experiments that have been initiated or controlled by officers of the Department of Agriculture of Trinidad and Tobago, up to the end of the year 1937. Numbers in heavy type refer to experiments described in the foregoing account, a total of seventeen (17) experiments in all. The remaining numbers (27) are the Type (A) code numbers of additional experiments for which definite results have not yet been obtained. A discussion of the conclusions based on the results of these additional experiments will be deferred to a future date.

Table VI.

Effect of Gypsum on Cacao Yields: Poole Estate.

Treatment.	Total $CaSO_4$ added p.p.m. Soil.*	Yields (lb. Dry Cacao per Acre).			Per cent. Increase or Decrease.
		1936.	1937.	Average.	
Gypsum alone	1,333	218	319	268	—10
Superphosphate and Gypsum	1,422	335	397	366	+22
Superphosphate alone	534	336	475	405	+36
Double Superphosphate	0	354	438	396	+32
Control (No additions)	0	260	338	299	—

* Assuming no losses through leaching.

PART II.—BIOCHEMISTRY OF CACAO.

OBSERVATIONS ON THE BIOCHEMISTRY OF CACAO KERNEL.

1. TANNIN AND CATECHIN.

By D. W. Duthie.

I. Introduction.

Preliminary investigations on the tannin-like components of fresh and fermented cacao beans were carried out at the College by McDonald (1), who applied Jensen's modification of Chapman's cinchonine sulphate method, and used, in addition, the goldbeaters' skin test and a formaldehyde method for estimating phlobaphenes. Chapman's method gave comparable results with both fresh and fermented kernel and shell, but the procedure is slow when applied to fresh shell and to fermented kernel. The goldbeaters' skin test was made roughly quantitative by grading the depth of staining under standard conditions, and this served as a check on the tannin determinations. These methods proved to be useful in preliminary study of the tannin problem in cacao, but it was found that the results obtained were erratic, and it was difficult to draw definite conclusions from the evidence obtained. McDonald points out that his work was restricted by sampling difficulties, since his study of the analytical methods occupied the greater part of the unusually short 1935-36 crop season, and the important samples were therefore obtained after the main Trinidad crop had been harvested.

In view of these difficulties, McDonald suggested that the tannin methods should be investigated further, and that samples of more typical material should be used. Accordingly, during the early part of the 1936-37 crop season, the methods of tannin determination were re-investigated and further modified, and the details of this work have been published elsewhere (2). An outline of the method finally adopted is given in a later section of this paper.

The biochemical factors investigated were (1) degree of ripeness, (2) botanical variety, (3) colour of bean, (4) effect of manures, and (5) effects of fermentation and drying. The samples as far as possible were typical of the particular factor in question, and were procured during the height of the crop season. Only the kernel was used, as the difficulty of estimating tannin in shell far outweighs the value of the results.

II. Methods of Estimation.

The details and discussion of the modifications introduced in the method of tannin analysis are given in a paper by the writer (2). A cold 40 per cent. acetone-water solution is used as extracting agent, as this proved superior to hot water extraction. Tannin is estimated in this extract by Chapman's cinchonine sulphate method, and the filtrate from the cinchonine tannate precipitate is treated with a formaldehyde-hydrochloric acid mixture, in accordance with Stiasny's test (3), giving what is considered to be a measure of the catechin and similar phenolic compounds. The procedure is as follows:—

Preparation of Sample.—The pods are opened in the laboratory, and the beans are immediately dropped into boiling water and boiled for three minutes, in order to destroy the oxidase and peroxidase enzymes which effect rapid oxidation of the phenolic substances. The shell is then removed, and the kernels ground by passing them through a mincing machine.

Extraction.—25 g. kernel (either fresh or fermented), are extracted overnight in 220 cc. of cold 40 per cent. acetone. The mixture is filtered through a 10.5 cm. Buchner funnel with a No. 41 Whatman paper which has been pre-coated with 2 g. kieselghur (or other filter-aid). The residue is washed with 20 cc. of 40 per cent. acetone, and the filtrate diluted to 250 cc. with water.

Tannin.—Triplicate 25 cc. aliquots of the extract are treated with 150 cc. of saturated cinchonine sulphate solution, left standing for 5 hours (or overnight), and decanted through a Gooch crucible having a pad of coarse asbestos which has been washed with half-saturated cinchonine sulphate, dried at 105°C. and weighed. The cinchonine tannate precipitate is washed with half-saturated cinchonine sulphate solution, dried overnight in a sulphuric acid desiccator, oven-dried at 105°C., and weighed. (Weight of ppt. $\times 0.534$ = wt. of tannin.)

Catechin and other Phenolic Compounds.—The filtrate and washings from the tannin estimation are left overnight with 50 cc. of formaldehyde-hydrochloric acid mixture (100 cc. conc. HCl, 100 cc. water, 150 cc. 40 per cent. formaldehyde). They are then boiled for one hour under an air condenser, filtered through a weighed asbestos Gooch crucible, dried at 105°C., and the precipitate weighed.

III. Experimental.

(1) Degree of Ripeness.

Samples of under-ripe, ripe and over-ripe pods were picked from five trees at River Estate. Each sample was a composite of several pods, varying from three to six, depending on the number available at the time. "Under-ripe" means that the pods were fully grown, green, with the pulp still compact, so that the beans were separated with some difficulty. At this stage, they would not normally be harvested by skilled estate pickers. "Ripe" pods had just reached the stage when they would be harvested; the pod colour was green with red or yellow, and the beans were easily separated. "Over-ripe" means that the pods had been left on the tree until they had

developed the full red or yellow colour, the pulp had shrunk considerably, and the pod gave the typical hollow sound on tapping; no decomposition had set in, and such pods would have occurred in considerable numbers in an average estate picking. Pods or beans showing signs of disease were rejected.

Table I gives the individual and average figures for five composite samples of each type. The under-ripe, ripe and over-ripe pods from each tree were all picked at the same time. The results are calculated as percentages of material dried to constant weight at 105°C.

A definite increase in both tannin and catechin occurs in passing from under-ripe to ripe, but comparison of ripe with over-ripe shows no definite difference. It seems that the formation of these polyphenolic compounds ceases when the pods reach maturity, and, from this point of view, it is immaterial at what stage of ripeness the pods are picked, providing that they are not diseased, and that they have reached the stage which an estate picker would recognise as ripe. This is important in view of later work, because in testing botanical type, effect of manures, &c., it was not always possible to obtain pods at precisely the same stage of ripeness.

Table I.

Forastero Pods—River Estate.	Colour of Pod.	Under-Ripe.		Ripe.		Over-Ripe.	
		Tannin %	Catechin %	Tannin %	Catechin %	Tannin %	Catechin %
Field 8, Tree X	Yellow	3.16	4.68	3.58	5.36	3.86	5.53
Field 8, Tree Y	Yellow	4.02	5.27	4.41	5.94	3.97	5.68
Propagation Field, Tree 35	Yellow	3.25	5.28	3.46	5.91	3.64	5.76
Propagation Field, Tree 1374	Red	3.43	4.90	4.73	7.73	5.08	6.55
Field 21, Tree Z	Red	3.41	6.20	3.86	5.87	3.84	6.08
Average		3.45	5.27	4.01	6.16	4.08	5.92

Table II.

	Pod Colour.	Bean Colour.	% Tannin.	% Catechin.
Criollo Type:				
1. Tobago	green	white	4.85	4.53
2. Tobago	green	white	3.93	5.28
3. Tobago	green	white	3.26	4.52
4. Tobago	red	white	4.81	5.12
5. River Estate, Trinidad	red	white	3.37	6.70
6. Tobago*	green	white	2.45	3.15
		purple	2.28	3.49
7. Tobago†	red	white	3.69	4.86
		purple	3.95	5.85
8. Tobago	green	v. light purple	3.72	5.14
9. Tobago	green	purple	3.10	5.42
Averages			3.58	4.91
Forastero Type:				
1. River Estate, Trinidad	yellow	purple	3.86	5.53
2. do. do.	yellow	purple	3.97	5.68
3. do. do.	yellow	purple	3.64	5.76
4. do. do.	red	purple	3.84	6.08
5. do. do.	red	purple	(5.08)	6.55
Averages			3.83	5.76
Calabacillo Type:				
1. Las Hermanas, Trinidad	yellow	purple	4.18	6.01

* White and purple beans occurred in the same pod and were analysed separately.
† Composite of 2 pods from the same tree, both containing white and purple beans.

(2) Botanical Type. Criollo *versus* Forastero *versus* Calabacillo.

There are very few true Criollo trees in Trinidad, and the experimental material of the Botanical Section of the Cacao Research Scheme has not yet reached mature production. Consequently, Criollo pods were obtained from Arden Estate, Tobago, where an area has been planted with budded Criollo trees. These were compared with what could best be described as "high-grade Forastero type" pods from River Estate, Trinidad, and one tree from this estate, which gives pods containing white beans, was also sampled for the Criollo group. One sample of low-grade beans of the Calabacillo type was obtained from Las Hermanas Estate, Trinidad, but further samples of this variety were not collected, since it is not certain that Calabacillo is a clear-cut variety in Trinidad.

Table II gives the results of this section of the work, the percentages being expressed on oven-dry basis.

The averages in Table II show slightly higher tannin and catechin contents of Forastero as compared with Criollo, the single Calabacillo sample showing still higher figures. Yet these differences are not sufficiently marked to account for the great increase in astringency of taste in passing from Criollo, through high-grade Forastero, to the lower grades of Forastero and to Calabacillo. The individual figures in the Criollo and Forastero groups overlap considerably, and on the whole it cannot be agreed that the astringent taste of low grade cacao is primarily due to the tannins in the fresh bean.

(3) Colour of Bean.

In Table II it will be seen that some of the Criollo type pods contained purple beans. Two samples contained both white and purple beans in the same pods, and these were separated for analysis. It has been suggested by the writer (4) that the presence or absence of purple colour might be an indication of other characteristics, and material was thus available to test this hypothesis as regards tannin and catechin contents. The rather meagre evidence given here, however, does not indicate that tannin or catechin content is in any way connected with bean colour.

(4) Effect of Manures.

The trees of a manurial experiment at River Estate were sampled in order to find whether the tannin content is affected by manuring with nitrogen, potash or phosphate. In this experiment, each treatment was replicated five times, and, in order to obtain a representative sample, two pods were picked from each plot, and the beans were mixed to form a composite sample. The manurial treatments had been carried on for three years previous to sampling. Only three treatments were sampled, namely (*a*) potash (*b*) nitrogen *plus* phosphate, and (*c*) control, as this was deemed sufficient for a preliminary test. Red pods and yellow pods were harvested separately. Table III gives the analytical figures for the three manurial treatments, and it must be concluded that the slightly higher tannin and catechin contents of the beans from the potash plots are not sufficiently striking to indicate any great difference in bean composition. At the same time, it should be noted that the cacao in this experiment was not uniform in quality, and further, the manurial treatment may not have been carried on long enough to affect markedly the physiological processes of the trees.

(5) Fermentation.

Uniformity of material is the chief difficulty when dealing with large samples of Trinidad beans, but a small scale fermentation experiment was set up with 40 lb. of wet cacao, picked from trees budded or grafted with the same clonal material, which could best be described as high-grade Forastero. The pods were all picked on the same day and were fully ripe; thus the sub-samples which were taken at different stages of fermentation and drying may be considered as truly representative.

The beans were fermented in the solar fermentary described by McDonald (5). A small sample of about 6 lb. weight was sun-dried without fermentation, while the main bulk of 40 lb. was sampled after fermenting for 2, 5, 9, 14 and 21 days. Small samples ranging from 4 to 7 lb. weight were sun-dried after 5, 9 and 14 days' fermentation, in order to make it possible to follow the changes on drying, and these were in turn sub-sampled at intervals during drying.

Table III.

Pod Colour.	Control.		Potash.		Nitrogen+Phosphate.	
	% Tannin.	% Catechin.	% Tannin.	%Catechin.	%Tannin.	% Catechin.
Yellow	3.04	5.35	3.59	6.14	3.30	5.57
Red	4.02	5.18	4.24	5.92	3.52	5.02
Averages	3.53	5.26	3.91	6.03	3.41	5.29

Changes During Fermentation.—Table IV gives the tannin and catechin percentages of kernel at different stages of fermentation, and also the corresponding figures for the sun-dried beans. The results in Table IV are for oven-dry material.

Table IV.

No. of Days.	Fermented.		Sun-Dried.	
	Per cent. Tannin.	Per cent. Catechin.	Per cent. Tannin.	Per cent. Catechin.
0	3.39	4.88	3.39	4.88
2	3.50	5.29	3.84	5.31
5	4.05	3.97	4.74	5.27
9	3.59	1.82	5.12	4.65
14	2.61	1.28	4.65	4.15
21	3.96	1.18	—	—
29	—	—	4.47	3.79

These figures show that, during fermentation, there is little change in the tannin percentage, but the catechin content drops rapidly after 5 days. The sun-dried beans show a slight tendency for tannin to increase, while the catechin remains more or less constant in amount.

Changes during Drying after Fermentation.—The 5, 9, 14 and 21-day samples from the fermentation box were sampled occasionally during sun-drying, in order to find what changes take place in the tannin and catechin contents. Table V gives the data for these samples, and shows, for comparison, similar figures for a sample of Criollo cacao which had been fermented and dried under estate conditions.

It will be seen from Table V that there is a very rapid loss of catechin during drying, even after 5 days' fermentation. It should be noted that no attempt was made to dry the beans slowly: they were sun-dried in small quantities. It is interesting to note that Criollo beans which had been fermented for only 60 hours showed tannin and catechin contents similar to Forastero beans which had been fermented for 9 days and dried for 12 days.

IV. Discussion.

The marked improvement in flavour which results from efficient fermentation and drying may thus be attributed, in part at least, to the almost complete disappearance of catechin, a result which was also obtained previously by Adam (6). The slow fermentation of purple beans would be explained if the catechin were associated in some way with the anthocyan pigment. Slight evidence in favour of this may be found in the following observation. When an acetone extract of fresh kernel is treated with saturated cinchonine sulphate solution, the purple pigment remains in solution and the precipitate is only slightly stained. But when the filtrate from this reaction is treated with the hydrochloric acid-formaldehyde mixture for precipitation of the catechin, the purple pigment disappears. The resulting precipitate, before boiling, is red with Forastero, and white with Criollo kernels, but the Criollo precipitate changes to red on boiling, being brick red as compared with the dark red of Forastero.

It must be remembered that two factors are involved in the "quality" of commercial cacao beans—namely the inherent "quality" of the fresh bean, and the treatment which it received during fermentation and drying. It has not been possible to produce from Forastero beans a product which resembles fermented Criollo beans, but the difference between unfermented and well-fermented Forastero cacao is as great as, if not greater than, that between well-fermented Forastero and Criollo. Since the tannin and catechin contents of fresh and fermented Criollo and Forastero kernels are similar, some other factor or factors must be responsible for the difference in "quality" which accompanies the difference in botanical type.

V. Summary and Conclusions.

(1) A method of estimating tannin in fresh and fermented cacao kernel has been modified to include a separate determination of catechin and similar phenolic substances. Extraction is carried out with cold 40 per cent. acetone, and tannin is determined by Chapman's cinchonine sulphate

Table V.

No. of days dried.	Fermented 5 days.		Fermented 9 days.		Fermented 14 days.		Fermented 21 days.	
	% Tannin.	% Catechin.	% Tannin.	% Catechin.	% Tannin.	% Catechin.	% Tannin.	% Catechin.
0	4.05	3.97	3.59	1.82	2.61	1.28	3.96	1.18
4	3.52	1.66	—	—	—	—	—	—
5	—	—	2.83	1.06	—	—	—	—
7	—	—	—	—	3.42	0.56	—	—
12	—	—	3.75	0.85	—	—	—	—
15	—	—	—	—	3.69	0.39	4.31	0.11
27	—	—	4.03	0.31	—	—	—	—

For Comparison.—Criollo beans from Tobago, fermented and dried under estate conditions gave 3.59 per cent. Tannin and 0.64 per cent. Catechin.

method. The filtrate from this, when treated with a formaldehyde-hydrochloric acid mixture, gives a measure of the catechin and similar phenolic substances.

(2) As a check on sampling of fresh beans, tannin and catechin were estimated in kernels from under-ripe, ripe and over-ripe pods. It was found that no marked change in tannin or catechin takes place after the pods have reached a stage which can readily be recognised as ripe.

(3) Fresh Criollo and Forastero beans were compared, but the difference in tannin and catechin contents is not sufficient to account for the difference in "quality" between these two types. One sample of Calabacillo beans gave figures similar to Forastero.

(4) White and purple beans from the same Criollo pod gave almost identical figures for tannin and catechin. No difference was found between Criollo pods which contained only white beans and those which contained only purple beans. Colour of bean, therefore, appears to have no relationship to tannin content.

(5) Forastero trees of a manurial experiment were sampled to find if the application of manures has any effect on the tannin compounds. The treatments sampled were potash, control, and nitrogen *plus* phosphate. The beans from the potash plots gave slightly higher tannin and catechin contents, but the difference was not sufficiently great to be conclusive.

(6) A small scale fermentation experiment was carried out in a solar fermentary with beans from trees budded or grafted with the same clonal material. No distinct change was found in the tannin content, but a rapid and very marked drop of catechin was observed during fermentation and drying.

(7) It is concluded that the tannin and catechin contents of fresh beans cannot be used as a criterion of "quality", but the drop in catechin content may have some significance in the ameliorating effect of fermentation.

Acknowledgments.

Thanks are due to Lt.-Col. G. Hinds Howell, of Arden Estate, Tobago, who supplied the Criollo beans, and to the Director of Agriculture and Mr. R. R. O'Connor, Manager of River Estate, Trinidad, for supplying the Forastero beans.

References.

1. McDonald, J. A.—"The Tannins in Cacao Beans". *6th Ann. Rep. Cacao Res.* 1936, p. 44.
2. Duthie, D. W.—"The Determination of Tannins in Cacao Kernel". *Analyst*, Vol. 63, No. 742 1938, p. 27.
3. Stiasny—Allen's Commercial Organic Analysis, 5th Ed. Vol. V, p. 76.
4. Duthie, D. W.—"Biochemical Problems in Cacao Production". *6th Ann. Rep. Cacao Res.* 1936, p. 48.
5. McDonald, J. A.—"A New Method of Curing Small Quantities of Cacao". *5th Ann. Rep. Cacao Res.* 1935, p. 48.
6. Adam, W. B.—"Determination of the Colour producing Constituents of the Cacao Bean." *Analyst*, Vol. 53, 1928, p. 369.